R0004

NATIONAL HIGHWAY TRAFFIL SAFETY ADMINISTRATION
WASHINGTON, D.C.

CONTRACTOR FINAL REPORT

TEST #

04

4 AFS

E. G. RIC''''RDSON

DOT HS-801 610

RESEARCH SAFETY VEHICLE PROGRAM (PHASE I) - VOLUME IV RSV CONCEPTUAL DEFINITION, FINAL PHASE I Bi-MONTHLY REPORT

Contract No. DOT-HS-4-00838

June 1975

Final Report

PREPARED FOR:

U.S. DEPARTMENT OF TRANSPORTATION

National Highway Traffic Safety Administration

Washington , D.C. 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No	2. Government Accession No	3. Recipient's Catalog No
DOT HS-801 610		

4. Title and Subtitle	5. Report Date
Research Safety Vehicle Program (Phase I) - Volume IV RSV Conceptual Definition; Final Phase I Bi-Monthly Report	JUNE 1975
	6. Performing Organization Code
7. Author(s) Patrick M. Miller, Saverio M. Pugliese, Melvin O. Ryder, Frank A. DuWaldt, Sanborn W. Chesley	8. Performing Organization Report No ZN-5450-V-14
9. Performing Organization Name and Address Calspan Corporation 4455 Genesee Street P.O. Box 235 Buffalo, New York 14221	10. Work Unit No 658 Series 11. Contract or Grant No DOT-HS-4-00838
12. Sponsoring Agency Name and Address Department of Transportation National Highway Traffic Safety Administration 400 Seventh Street, S.W. Washington, D.C. 20590	13. Type of Report and Period Covered Final Technical Report January 1974 to April 1975 14. Sponsoring Agency Code

15. Supplementary Notes

Volume IV of four volumes

16. Abstract

A preliminary conceptual design intended to meet the specifications recommended in Volume III for the Research Safety Vehicle (RSV) is presented. It is expected that this preliminary design will be the basis for further development in Phases II and III of the program. The design assumes derivation of the RSV from a production automobile. In this part of the study, numerous candidate base vehicles were considered. The rationale behind the selection of the particular vehicle (designated the C-6) is discussed. Extensive data on the geometric, performance and crash properties of the C-6 are presented.

This preliminary design considers base vehicle alterations relative to styling, occupant/cargo packaging, running gear and crash safety. The dimensional and style characteristics recommended for the RSV were verified by development of a full-scale vehicle mock-up. Major design attention was placed on bumpers, vehicle structure and compartment interior components. A soft face bumper intended to provide improved pedestrian and vehicle protection is incorporated into the vehicle front. An integrated crashworthy vehicle structural design which improves passenger compartment integrity as well as reduces vehicle aggressivity is proposed. Both advanced air bag and lap/shoulder belt concepts are suggested as being appropriate for further consideration in Phase II of the RSV program.

17. Key Words		18. Distribution Statement
automobile trends	producibility	Document is available to the public through the National Technical Information Service, Springfield Virginia 22161
safety	pedestrian protection	
natural resources	occupant protection	
accident data		
crashworthiness		

19. Security Classif (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
unclassified	unclassifi d	151	

Form DOT F 1700.7 (8-69)

FOREWORD

This report presents the conceptual design aspects of a study of vehicle characteristics suitable for an automobile not exceeding 3000 lbs. weight that would be introduced in the mid-1980's. It addresses a part of the findings of the Phase I effort in a study entitled "Research Safety Vehicle" (RSV) which is intended to address passenger car safety performance predicated on projected requirements of U. S. traffic in the mid-1980's. Phase I entails conceptual definition of the RSV to the subsystem level and is being performed in the context of a competition--the winners of which will embark on Phase II, Total Vehicle Design.

Reporting of the Calspan Phase I effort encompasses the following four volumes (of which this is Volume IV):

Volume I - RSV Introduction and Executive Summary
Calspan Report No. ZN-5450-V-11

Volume II - RSV Program Definition and Foundation
Calspan Report No. ZN-5450-V-12

Volume III - RSV Characterization and Performance Specification
Calspan Report No. ZN-5450-V-13

Volume IV - RSV Conceptual Definition; Final Phase I Bi-Monthly Report
Calspan Report No. ZN-5450-V-14

The above titles and the section numbering system were specified by NHTSA in February 1975.

This report is submitted in partial fulfillment of a program of research conducted by Calspan Corporation for the National Highway Traffic Safety Administration under Contract No. DOT-HS-4-00838. Contract Technical Manager for this project is Mr. Jerome M. Kossar, NHTSA.

The opinions and findings expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

This report has been reviewed and is approved by:

Edwin A. Kidd

Edwin A. Kidd, Head
Transportation Safety Department

ACKNOWLEDGMENTS

The authors are indebted to the Chrysler Corporation for important inputs and discussions over the whole range of RSV considerations. Major assistance was given by Messrs. Robert M. Sinclair, Leonard L. Baker, Edward D. Heins, Donald R. Wolfslayer, William M. Brownlie, Dr. Jack E. Thompson, and particularly Mr. Gerald E. Frig who acted as coordinator.

Calspan Corporation engineers who contributed in particular areas included Messrs. John Garrett, Daniel Massing, Sheridan Smith, Roy Rice, Kenneth Perchonok, John Bartz, and Dr. Edwin A. Kidd. Ms. Barbara Kunkel did a major service in performing library functions. Secretarial help from Miss Alesia E. Kudela, Mrs. Maureen Ball, Mrs. Joan Lus and Miss Janice Mulartrick is acknowledged.

ABSTRACT

A preliminary conceptual design intended to meet the specifications recommended in Volume III for the Research Safety Vehicle (RSV) is presented. It is expected that this preliminary design will be the basis for further development in Phases II and III of the program. The design assumes derivation of the RSV from a production automobile. In this part of the study, numerous candidate base vehicles were considered. The rationale behind the selection of the particular vehicle (designated the C-6) is discussed. Extensive data on the geometric, performance and crash properties of the C-6 are presented.

This preliminary design considers base vehicle alterations relative to styling, occupant/cargo packaging, running gear and crash safety. The dimensional and style characteristics recommended for the RSV were verified by development of a full-scale vehicle mock-up. Major design attention was placed on bumpers, vehicle structure and compartment interior components. A soft face bumper intended to provide improved pedestrian and vehicle protection is incorporated into the vehicle front. An integrated crashworthy vehicle structural design which improves passenger compartment integrity as well as reduces vehicle aggressivity is proposed. Both advanced air bag and lap/shoulder belt concepts are suggested as being appropriate for further consideration in Phase II of the RSV program.

TABLE OF CONTENTS *

* Contents of all four volumes (volumes separately bound) in accordance with NHTSA format instructions.

Table of Contents (Contd.)

Table of Contents (Contd.)

Table of Contents (Contd.)

Table of Contents (Contd.)

Table of Contents (Contd.)

Table of Contents (Contd.)

LIST OF FIGURES

List of Figures (Contd.)

List of Figures (Contd.)

List of Figures (Contd.)

LIST OF TABLES

6. RSV CONCEPTUAL DEFINITION

Contained in this volume are background studies and considerations that conceptually define a preliminary design of the RSV This is the fourth in a sequence of final report volumes listed in the Foreword.

The objectives of the Research Safety Vehicle (RSV) program as defined by the National Highway Traffic Safety Administration is to provide research and test data applicable to automobile safety requirements for the mid-1980's, and to evaluate the compatibility of these requirements with environmental policies, efficient energy utilization, and consumer economic considerations. Accordingly, it is recognized that in the performance of this program, factors extending well beyond a strict consideration of safety are to be investigated. However, protection of vehicle occupants and pedestrians is of major concern in this effort.

The overall program is expected to be implemented in four distinct phases as outlined below:

PHASE I
- a. Define program
- b. Develop performance specification
- c. Develop preliminary design
- d. Develop and submit proposal for Phase II

PHASE II
- a. Perform systems engineering and integration analyses
- b. Develop total vehicle design
- c. Develop and submit proposal for Phase III

PHASE III
- a. Refine and optimize design
- b. Fabricate test vehicles

PHASE IV
- a. Test and evaluate vehicles (Anticipated to be competitively awarded to a contractor other than those who may be awarded either Phase I, II or III)

As indicated above, Phase I is essentially constituted as a foothold effort which will provide the foundation for the complete program Within Phase I, vehicle characteristics, performance specifications and a preliminary design were established. This fourth report volume is limited to the preliminary design task of Phase I and present Calspan recommendations for a vehicle design felt to be compatible with the vehicle characteristics and specifications outlined in previous report volumes.

Prior to reviewing some of the more salient results, it may be helpful to remind the reader of Calspan's general philosophy, expressed in Volume I, which tends to shape its RSV program. Notwithstanding the fact that manufacturers annually proclaim advances in their product, in reality the automobile undergoes extremely small changes on a year-to-year basis Indeed, accumulation of such changes over a period of years, say the last 25, demonstrates only modest alterations in the basic mechanisms of the automobile. That is, the design and fabrication materials of present automobiles are not notably different from those of a generation ago. Thus, it is our belief that the automobile has and will continue to change only in an evolutionary manner. In this respect, a decade constitutes a very brief period and it is likely that automobiles introduced in the mid-1980's will be quite similar to many vehicles in current production. Reinforcing this view is the developing awareness that a massive commitment of capital will be required in energy and resources development--and new capital may not be available to realign the transportation industry even if it were desirable.

On the other hand, consumers can exert considerable influence on the types of automobiles that can be marketed. Taking into account both domestic and foreign vehicles, American consumers have a wide range of automobiles from which they can make selections and thereby demonstrate what characteristics they wish to have in motor vehicles. Thus, significant changes in the type of vehicles being manufactured and marketed can occur rather rapidly as a result of changes in consumer demand. It is anticipated that shifts of this type will be the more prominent during the time period in question.

Finally, it must be recognized that automobiles represent, for the most part, compromises between various alternatives. The best choices cannot always be established in terms of precise scientific methodology. Rather, the product must frequently be derived from rational, human judgments based upon estimates of need and demand. In addition, because automobiles must meet diverse needs of individuals, or families, there cannot be a unique vehicle which satisfies all. It therefore follows that the marketplace must continue to provide a wide choice of vehicles in order to meet the diverse needs of most consumers. Indeed, it might be persuasively argued that in view of worldwide petroleum limitations, a greater availability of power systems including non-petroleum based systems would be highly desirable.

As extensively discussed in previous report volumes, Calspan recommended that the RSV program pursue development of a lightweight, family automobile. It was felt that such an automobile, weighing under 3000 lbs. and seating 4-5 full size occupants will be typical of the more common automobile operating in America during the latter 1980's. There are any number of avenues which could be taken in development of such a vehicle. In the following, we discuss in detail Calspan's recommended approach, provide background rationale for selecting the base vehicle approach, present performance data on the base vehicle and indicate, particularly at the subsystem level, design concepts necessary to derive the RSV from the base vehicle.

6 1 Basic Approach

As indicated in this discussion, we recommend that the RSV be a derivative from a current production vehicle. This approach is believed to be consistent with our often stated position that the RSV should recognize the evolutionary nature of automobile design; yet, that automobiles suitable for the latter 1980's must undergo substantial change in design, at least from that currently practiced in the United States. Although these two statements may appear to be in conflict, it was found after careful review of automobile design practices on a worldwide scale that there exists a number of attractive candidate automobiles suitable for a base vehicle

Thus, an automobile encompassing many of the characteristics discussed in previous volumes of this report can indeed be based upon evolutionary departures from some current production cars.

As further developed below, Calspan's recommended approach would base the RSV on a production automobile. The recommended characteristics for a vehicle suitable for the mid-1980's as developed in previous volumes of this report left open the approach to actual vehicle development. However, when attempting to translate these characteristics and specifications into an actual vehicle, it became necessary to actually determine how the final vehicle would be developed. Two basic approaches were considered, (1) development of a completely "new" vehicle where off-the-shelf components from many vehicles would be integrated into a single system, and (2) modifying a production vehicle into the RSV. Primarily because of the stringent producibility requirements envisioned for the RSV, the first approach was rejected as being impractical and a search for a reasonable base vehicle was undertaken.

To be a viable program and provide impetus to automobile design, the RSV program should result in a vehicle which is basically compatible with automotive mass production methods. The goal of providing producibility in a prototype might be eluded in the overall program unless certain precautions are taken. It is well recognized that present cars for the most part represent an evolutionary change from previous vehicles. Thus, cars carry over many components from previous designs. Principally because of the producibility objective we believe the practice should be maintained to the greatest extent feasible in the RSV program.

It was also recognized that RSV program resources preclude the development of a complete ground-up vehicle. Therefore, an approach which intended to develop a "new" vehicle system would essentially resort to selection of various vehicle components from different automobiles and then integrate them into a single vehicular system. This basic approach appears to be the route taken by some American contractors on the previous ESV program. Apart from the fact that the final vehicle must then necessarily represent a "cobbled" design, the method does not permit an effective means for weight control. It is well known that weight control is an important factor in vehicle design (particularly with smaller vehicles), and most automobiles do indeed represent effective integration among various components so as to result in a reasonable minimum weight vehicle. Thus, a ground-up vehicle development using an "off-the-shelf" component would either lose this essential element or prohibitive engineering or redesign would be required.

With the base vehicle approach, on the other hand, a well integrated system can be presupposed. Of course, this requires that considerable care be exercised in selecting the base vehicle so that such an assumption is warranted. Importantly, it then follows that major program resources can then be directed to advancement of the more important safety aspects of the vehicle. Obviously, the strength of the above arguments depends upon the degree to which the base vehicle conforms to the desired RSV characteristics. If the base vehicle must be modified too extensively, many of the advantages delineated above will be seriously diminished. Therefore, the search for a suitable tentative base vehicle has been an important part of the RSV effort. This vehicle selection process is discussed in the next section.

6.2 Base Vehicle Characteristics

When selecting a base vehicle, it was necessary to insure that the base vehicle be representative to a reasonable degree of common automobile design practice, yet, also provide for straightforward development of the properties deemed appropriate for later 1980 family type automobiles. In addition to identifying reasonable weight and occupant/cargo properties, it was also necessary to consider its performance and safety characteristics, both on an absolute basis and relative to RSV recommendations.

6.2.1 Vehicle Selection Process

The choice of vehicle(s) which will ultimately be modified and developed into an RSV will influence the resultant RSV characteristics. For this reason, the candidate vehicle should meet, or come as close as possible to, the general physical criteria previously recommended for the RSV. No currently manufactured vehicle, either domestic or foreign, meets all of these independently developed goals. Therefore, the most important specifications, namely weight and occupant/cargo packaging, were viewed as principal guidelines for discriminating between good and bad choices of a candidate automobile.

The weight limitation of 3000 lbs. narrows the choice to vehicles comprising the subcompact and compact vehicle classes. This weight limit is further reduced because upgrading of the candidate vehicle with respect to safety systems will require weight additions to both the structure and interior. In order to meet the 3000 lb. weight limit, the candidate vehicle should therefore weigh less than 2500-2600 lbs. We note here that technically it is more feasible to take a smaller existing vehicle and expand it to meet the design configuration than it is to take a large base vehicle and contract its dimensions.

Review of domestic and foreign vehicles indicates that a majority of foreign vehicles can meet this upper weight bound; only two domestically produced vehicles, Vega and Pinto, marginally meet the requirement. The Vega and Pinto have nevertheless been eliminated from consideration because they are extremely limited in terms of passenger and cargo space. Improving the interior and cargo packaging of these vehicles to a point at which they would be consistent with the expectations for a family car in the 1980's would disproportionately affect the resource allocations necessary to modify the vehicles. The disparity between the recommended RSV characteristics and those of the 1975 Vega and Pinto is seen in the dimensional data presented in Tables 6-1 and 6-2. The rear compartment dimensions (leg room, hip room, and shoulder room) and cargo capacity would require excessive efforts

Table 6-1
EXTERIOR CAR AND BODY DIMENSIONS (INCHES)

	SAE Ref. No.	VEHICLE 3-dr. Sedan 1975 Pinto	2-dr. Hatchback 1975 Vega	Chrysler C-6	RSV Range
CURB WEIGHT**		2613	2558	2180***	2500-3000
Width					
Tread - Front	W101	55.0	54.8	55.7	
Tread - Rear	W102	55.8	53.6	53.5	
Maximum overall car width	W103	69.4	65.4	66.1	70-74
Body width at No 2 pillar	W117	66.5	64.6		
Max front doors open	W120	--	146.8		
Max rear doors open	W121				
Length					
Body O to front of dash	L 30	-3.2	- .8		
Wheelbase	L101	94.5	97.0	102.5	105-115
Overall car length	L103	169.0	175.4	167.0	175-190
Overhang - front	L104	37.5	35.2	29.7	
Overhang - rear	L105	37.0	43.2	34.9	
Body upper structure length	L123	103.4	95.0		
Body O line to C/L of rear wheel	L127	85.0	86.0		
Body O line to w/s cowl point	L130	7.9	10.9		
Height					
Passenger Distribution (front & rear)	*	2-1	2-2		
Trunk/Cargo load (lbs)	*	200			
Overall height	H101	50.5	50.0	54	55-60
Cowl height	H114	35.4	35.3		
Deck height	H138	31.5	3.7		
Rocker panel - front: To ground	H112	7.4	6.7		
Rocker panel - front: From front wheel C/L	H112	---	---		
Bottom of front door to ground	H133	---	8.9		
Rocker panel rear: To ground	H111	6.9	6.2		
Rocker panel rear: From rear wheel C/L	H111	---	---		
Bottom of rear door to ground	H135	---	---		
Windshield slope angle	H122	60.0	58.0		
Ground Clearance					
Bumper to ground - front	H102	13.4	14.9		
Bumper to ground rear	H104	12.6	13.2		
Angle of approach	H106	21.5	20° 16'		
Angle of departure	H107	20.9	21° 14'		
Ramp breakover angle	H147	---	15° 6'		
Rear axle differential to ground	H153	---	6.3		
Min running clearance (Specify)	H156	---	4.9 (a)		

*All measurements are made at the stated passenger and trunk/cargo loadings

** No options included

(a) Catalytic Converter

*** Does not meet FMVSS's

Table 6-2
INTERIOR CAR AND BODY DIMENSIONS (INCHES)

	SAE Ref. No.	VEHICLE 1975 Pinto	1975 Vega	Chrysler C-6	RSV Range
Front Compartment					
H Point to body O line	L31	42.5	43.6		
Effective head room	H61	37.3	37.1	37.2	37-39
Max eff leg room - accelerator	L34	40.8	43.5	41.1	40-42
H Point to Heel point	H30	8.6	7.8		
H Point travel	L17	5.0	6.5		
Shoulder room	W3	52.5	51.3	54.7	54-60
Hip room	W5	51.8	47.2	---	54-60
Upper body opening to ground	H50	47.0	45.9		
Rear Compartment					
H Point couple distance	L50	28.7	27.4	31.2	
Effective head room	H63	35.8	35.3	36.4	37-39
Min effective leg room	L51	30.4	29.6	36.1	35-38
H Point to Heel point	H31	---	10.4		
Min knee room	L48	2.2	-3.5		
Rear Compartment room	L3	---	24.3		
Shoulder room	W4	51.0	49.2	53.5	54-60
Hip room	W6	42.0	42.5	---	54-60
Upper body opening to ground	H51	---	---		
Luggage Compartment					
Usable uggage capac y (cu ")	V1	6.3	8.7	11 6	14-19
Liftover height	H195	28.5	29.03		
Position of spare tire storage		Flat (in well)	Flat		
Method of holding lid open		Gas Cylinders	Gas Springs		

to get them to fall within the recommended RSV range. The high occupant/cargo-to-weight efficiency envisioned for the RSV cannot be met by current conventional American automotive designs.

Accordingly, the design of all foreign vehicles imported to the U. S. were reviewed. Within this collection there are a number of vehicles which meet the requirement. For example, the Audi 100LS (2400 lbs.), Saab 99LE (2500 lbs.) and Volkswagen Dasher (2100 lbs.) all meet the guidelines and would have been attractive possibilities for the program. These vehicles are mentioned here only to acquaint the reader with the type of automobile believed appropriate as a base vehicle for the RSV program. It is noteworthy that all of these vehicles have characteristics distinctly different than typical American cars. That is, they are higher, have less vehicle length devoted to the hood and trunk with correspondingly less front and rear overhang. In addition, all of these vehicles employ front engine, front wheel drive systems. This factor, as discussed in detail later, has a major effect on vehicle weight, occupant packaging and vehicle crashworthiness.

Because of the Calspan partnership with Chrysler in the RSV program, we reviewed Chrysler vehicles (both domestic and foreign productions) to determine if any were suited for a RSV type development project. Chrysler France has under development a vehicle, designated the C-6, which is well suited to the purposes of the program. This vehicle will be introduced in Europe early this fall. It has a curb weight of 2300 lbs. and provides accommodations for five passengers. The basic C-6 vehicle design is illustrated in Figure 6-1. It is noteworthy that this car uses a transverse front engine, front wheel drive system. Although there are no current plans to immediately market the C-6 in the U. S., it is expected that in the European market the C-6 will be competitive with the three foreign cars discussed previously. Thus, there is good reason to believe that a RSV developed from this vehicle would find acceptance within a large segment of the American market, e.g., witness the interest in the VW Dasher and Audi 100LS automobiles.

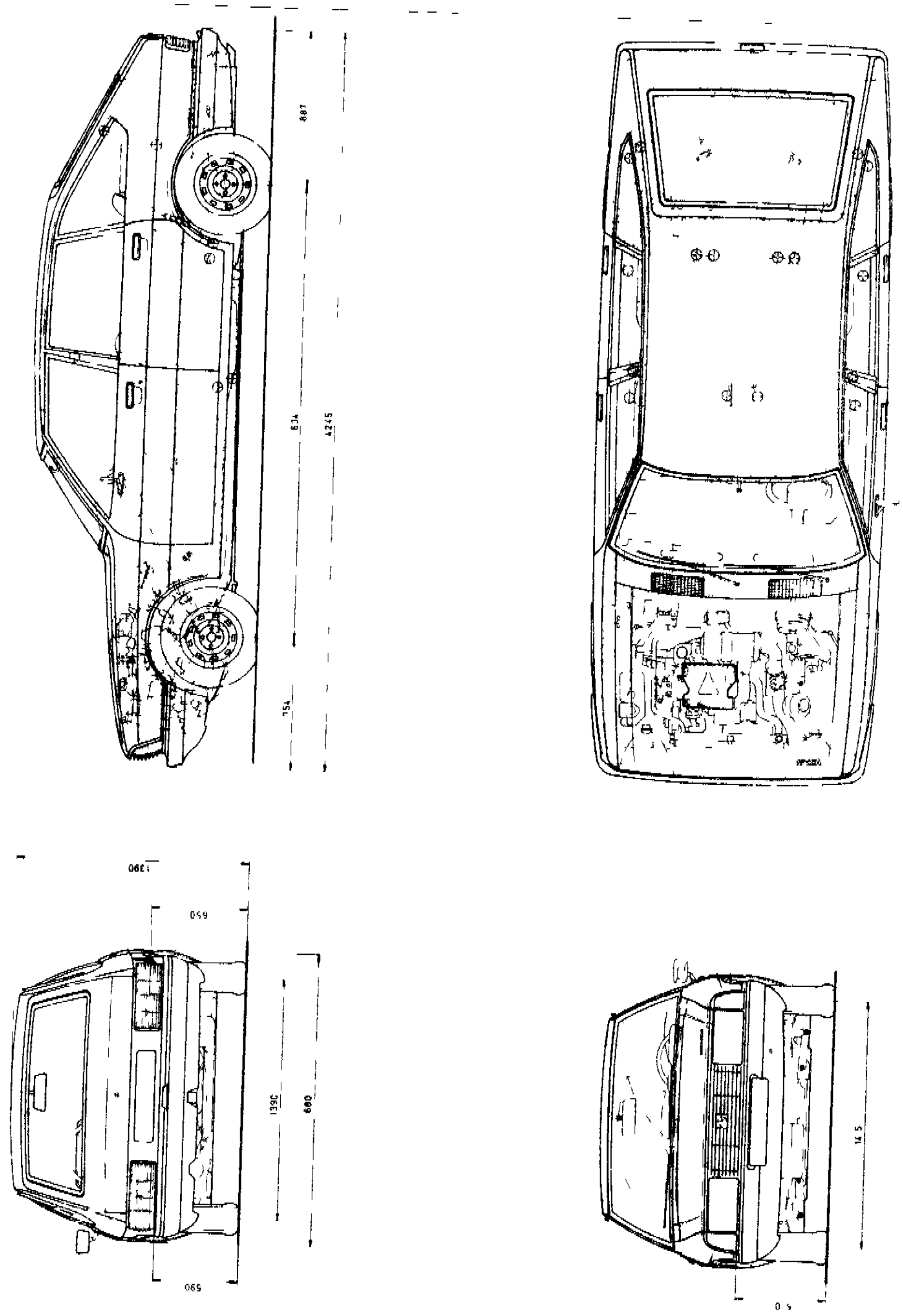


Figure 6-1 C-6 ILLUSTRATION (DIMENSIONS IN MM)

Component weight breakdown for the C-6 is provided in Table 6-3. It is noted that the total weight is 1043 kg. or 2300 lbs. As discussed later (see Section 6.3) we do not expect to provide a spare tire and fuel tank capacity will be about 10 gallons rather than 15 gallons as is the case with the C-6.* Thus, the base vehicle to be used as a starting point for the C-6 will be close to 2200 lbs.

Another feature that aroused interest in the C-6 is its transverse front engine, front wheel drive configuration. The merits of this configuration have been discussed in previous report volumes. These include:

- Interior comfort is enhanced because there is no tunnel.

- Improved frontal crashworthiness because of a better engine/firewall load distribution and less engine/compartment intrusion.

- Reduced fire hazard potential because the gas tank can be placed between the rear wheels.

- The floor of the trunk can be lowered because of gas tank relocation. Therefore, increased cargo capacity is available.

For these reasons, it is felt that the C-6 is an attractive candidate for a base vehicle. We note, however, that the C-6 dimensional characteristics are not totally within the ranges previously recommended for the RSV. Therefore, a number of studies as outlined below were performed to determine the feasibility of bringing the C-6 into full compliance with the recommended characteristics:

---

*Note, Table 6-3 assumes full capacity for fuel, oil and water.

Table 6-3

C-6 COMPONENT WEIGHTS

COMPONENT	WEIGHT KG.	WEIGHT LB.
BODY IN WHITE	259	571
OPERATING HARDWARE	17	37
INTERIOR LAMPS, SWITCHES, INSTRUMENTS	3	7
EXTERIOR ORNAMENTATION	10	22
TRIM PANELS	28	62
SEATS	42	93
SEALERS, W/STRIPS, INSULATORS	62	137
GLASS	37	82
CONVENIENCE ITEMS	4	9
INTERIOR MOULDING & ORNAMENTATION	0.5	1
INSTRUMENT PANEL & CONSOLE	11	24
BODY PAINT	7	15
ENGINE AND COMPONENTS (WITH CLUTCH AND TRANSMISSION) / FINAL DRIVE	177	390
FRONT STRUCTURE & SUSPENSION	19	42
FRONT SUSPENSION	42	93
REAR SUSPENSION	42	93
STEERING	16	35
BRAKES	50	110
WHEELS AND TIRES	75	165
GEAR SHIFT CONTROLS / CLUTCH PEDAL AND LINKAGE / PARKING BRAKE AND CONTROLS	7	15
EXHAUST SYSTEM	13	29
FUEL SYSTEM	10	22
BUMPERS	19	42
CHASSES ELECTRIC	15	33
TOOLS	4	9
OIL - GREASE - FUEL & WATER	59	130
WIRING AND CLIPS	4	9
HEATER	10	22
WINDSCREEN WASHER	0.5	1
TOTAL CURB WEIGHT	1043	2300

- Increase the frontal dimension (from dashpanel to leading car edge) by 8" to 10". This change would permit addition of a soft face bumper to the existing vehicle structure as well as provide a small increase in wheel base. The former change is necessary to accommodate the pedestrian (also damage reduction) bumper envisioned for the RSV while the latter change would enlarge frontal crush capacity.

- Stretch the passenger compartment by 2" or 3" at the center pillar location. This change would essentially increase the H-point couple distance between the front and rear seat occupants. Simultaneous with this change, the B-pillar could be redesigned to provide increased strength during both longitudinal and lateral collisions.

- Increase vehicle height by about 2". This would permit a slight change in seating height, particularly in the rear seat, thereby providing for a small increase in both leg and shoulder room dimensions.

- Widen the vehicle by 4" to 8". This change would appear to be necessary if both the basic interior dimensions are to be maintained and the improved side impact crashworthiness is to be developed.

If all of these modifications were made, the base vehicle would indeed conform very closely to the basic dimensional characteristics independently derived as being appropriate for the RSV. There appears to be no fundamental technical reasons why these could not be fully incorporated into the base vehicle either in prototype or production versions. Nevertheless, keeping in mind the resource limitations on the RSV program, it may not be appropriate to incorporate all of these changes into the vehicle; and thereby, the resources could be more productively used in other areas. The specific configuration changes which are recommended for the RSV design are discussed in Section 6.3 of this volume.

Other areas also exist in which the C-6 will deviate from the RSV recommendations. For example, because the C-6 will be produced for a non-American market, many optional features commonly viewed as standard on American cars, will not be available. These include automatic transmission and air conditioning. It is recognized that the American public would want these options, but further development in this area would not be consistent within the RSV program resources. Also, the present developmental work on the C-6 is restricted to a one vehicle configuration, i.e., a five door sedan. The RSV should, however, address a family of vehicles; a four or five door sedan would be the baseline car from which offshoots such as station wagons, hatchbacks and sports cars could be produced. Delivery of the RSV should, therefore, include documentation on these variants with regard to their configurations and possibly unique safety problems.

In the following section, the performance characteristics of the C-6 and possible effects of the proposed modifications on these characteristics are discussed.

6.2.2 Vehicle Performance Characteristics

The estimated performance characteristics of the C-6 are similar to those of the 1974 Audi Fox. Data on fuel economy and acceleration capabilities for a number of vehicles, including the C-6, are presented in Figure 6-2. The present C-6 displays improved fuel economy over domestic vehicles (approximately 3 miles/gal improvement in the urban cycle and 6 miles/gal at 70 MPH road load), while at the same time maintaining comparable acceleration performance characteristics.

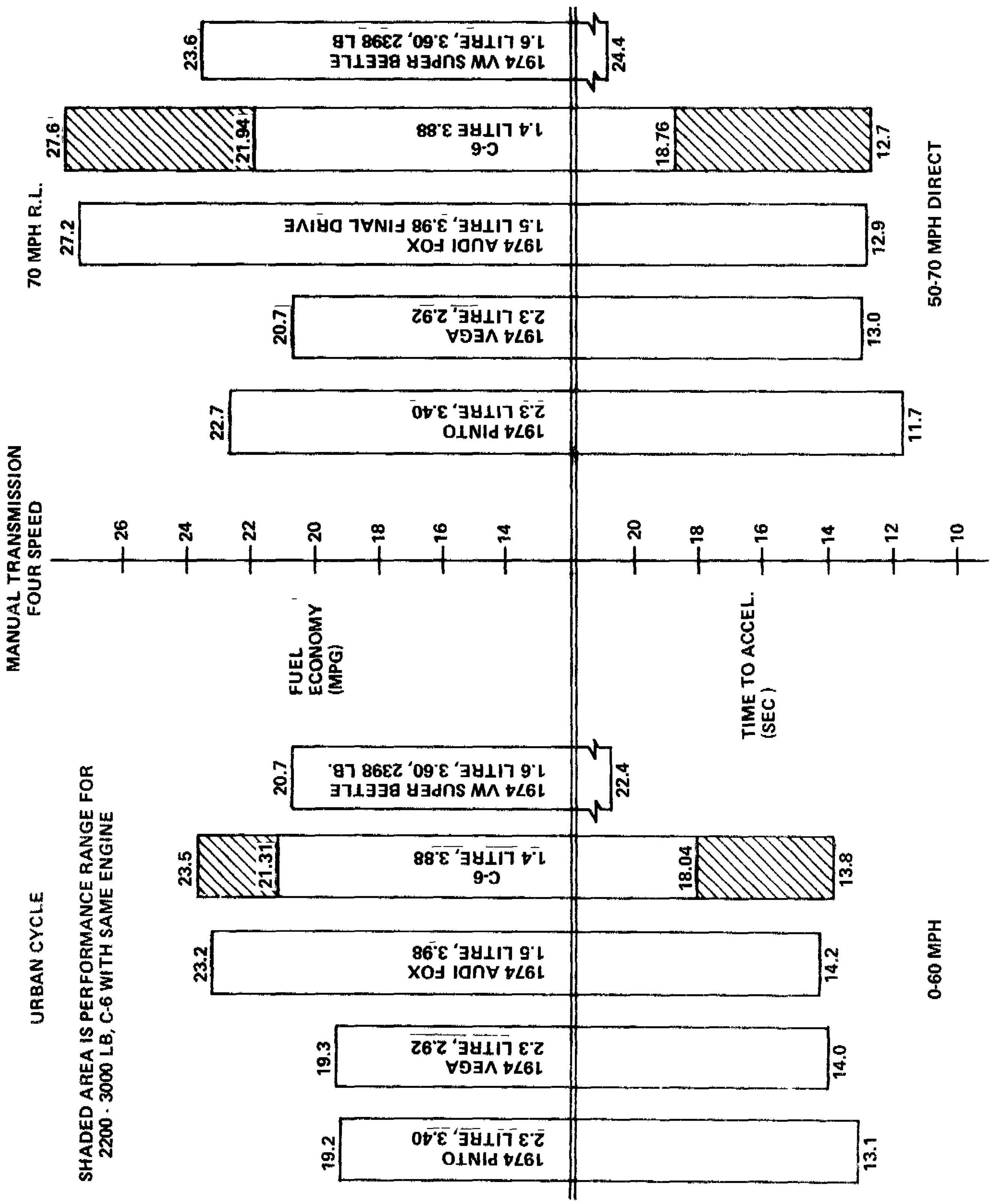


Figure 6-2 PERFORMANCE COMPARISON

It is realized, however, that both fuel economy and acceleration performance will be downgraded from present levels because of the weight additions that will be required for safety upgrading of the baseline C-6. For this reason, a range of performance is indicated in Figure 6-2 based on present vehicle weight and at 3000 lbs. (vehicle size effects were not considered in this simulation). It is seen that at 3000 lbs., fuel economy of the C-6 would still be above the level provided by domestic vehicles for the urban cycle. Fuel economy would be comparable for the 70 MPH road load condition.

Although fuel economy for a 3000 lb. C-6 would be slightly better than 1974 domestics (Pinto and Vega), the acceleration performance would be worse. The role which acceleration performance plays as an accident avoidance measure is not known. There does not appear to be any indication that vehicles such as the VW Beetle are more accident prone than any other lightweight vehicles because of the low acceleration potential. Further investigations were conducted on performance degradation as a result of incremental weight changes on the C-6 assuming no engine change. These data are presented in Figure 6-3.* It is readily evident from the curves that acceleration capabilities are affected most by weight changes--fuel economy is affected also but not nearly as much.

The performance envelope for fuel economy and acceleration capabilities (from 2200 to 3000 lbs.) in Figure 6-3 marginally meets the goals envisioned for a vehicle in the 1985 time frame. Fuel economy, in particular, should be as high as possible. However, occupant/non-occupant safety is the number one priority; and therefore, no engine development is envisioned as part of the RSV effort. A production engine will be used, and possible alternative engines identified.

* Performance data shown in Figure 6-3 is for a C-6 vehicle having a 1440 cc engine. As discussed in Section 6.3, stringent fuel economy requirements might suggest an even smaller engine for the final RSV.

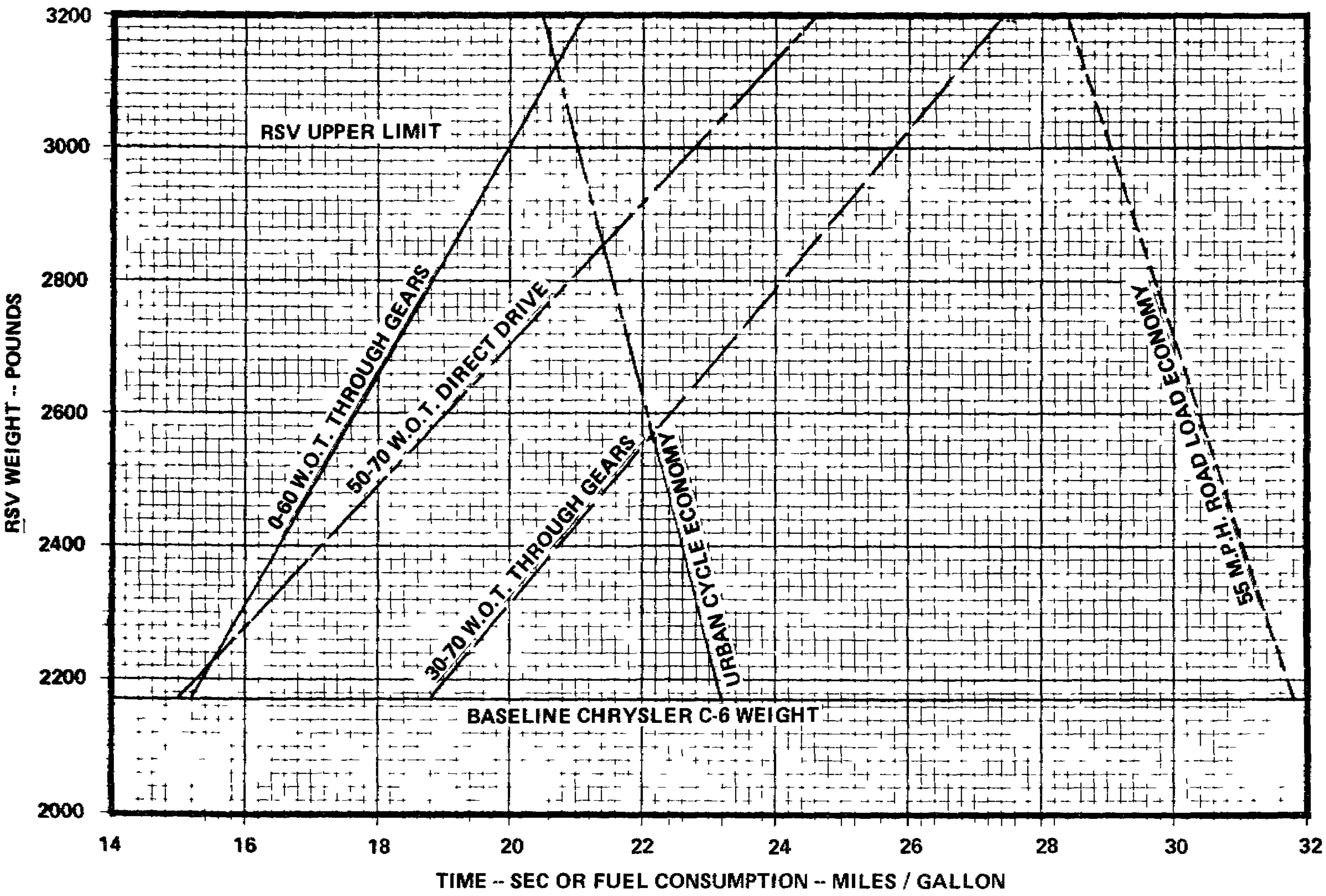


Figure 6-3 PROJECTED RSV PERFORMANCE AND ECONOMY TRENDS

6.2.3 Accident Avoidance Characteristics

The following vehicle properties that are related to accident avoidance were discussed in previous RSV reports (Volumes II & III):

- braking
- steering
- lateral acceleration and control at breakaway
- directional stability
- visibility from the vehicle
- visibility of the vehicle

It is difficult to directly relate accident avoidance characteristics to observations in the field. The attempts to do so were summarized in Volume II and are shown in Figure 6-4. Relatively minor contributions to causation have been assigned to the vehicle.

Partial substantiation of the accident investigation findings that vehicle limitations are not strong accident causal factors is observed in instrumented handling tests. Calspan conducted an investigation that gives a first approximation of the degree to which a sample of drivers used the available maneuvering potential of a car (braking, cornering, acceleration) over obstacle courses and in-traffic (Ref. 6-1). A speculative metric was adopted--the area of the g-g diagram (i.e., longitudinal and lateral acceleration components) developed during the maneuvers normalized by the idealized limits for the vehicle. The idealized diagram for the test car used is shown in Figure 6-5. About 0.6 was the best performance measure achieved in the best hard cornering run (four performance passes were made by each of seven drivers). No absolute claims can be made on the basis of these embryonic techniques; but the observations do support the belief that current vehicles have more maneuvering capability than the driver extracts (except under adverse road conditions such as icing). On-the-road tests showed that 0.3 g was seldom exceeded and 0.45 g was the maximum combined braking and

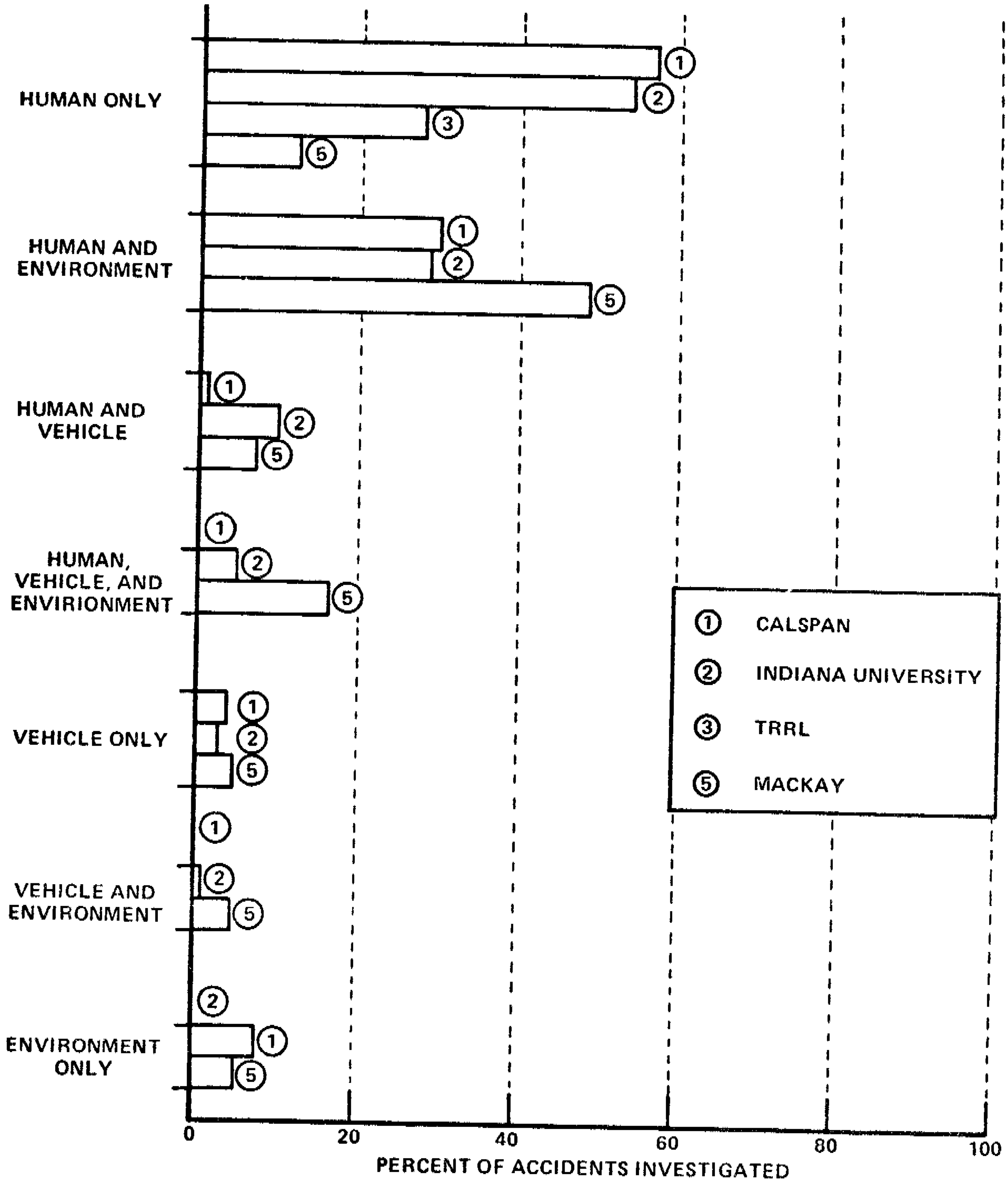


Figure 6-4 INTERACTIONS OF CAUSAL FACTORS

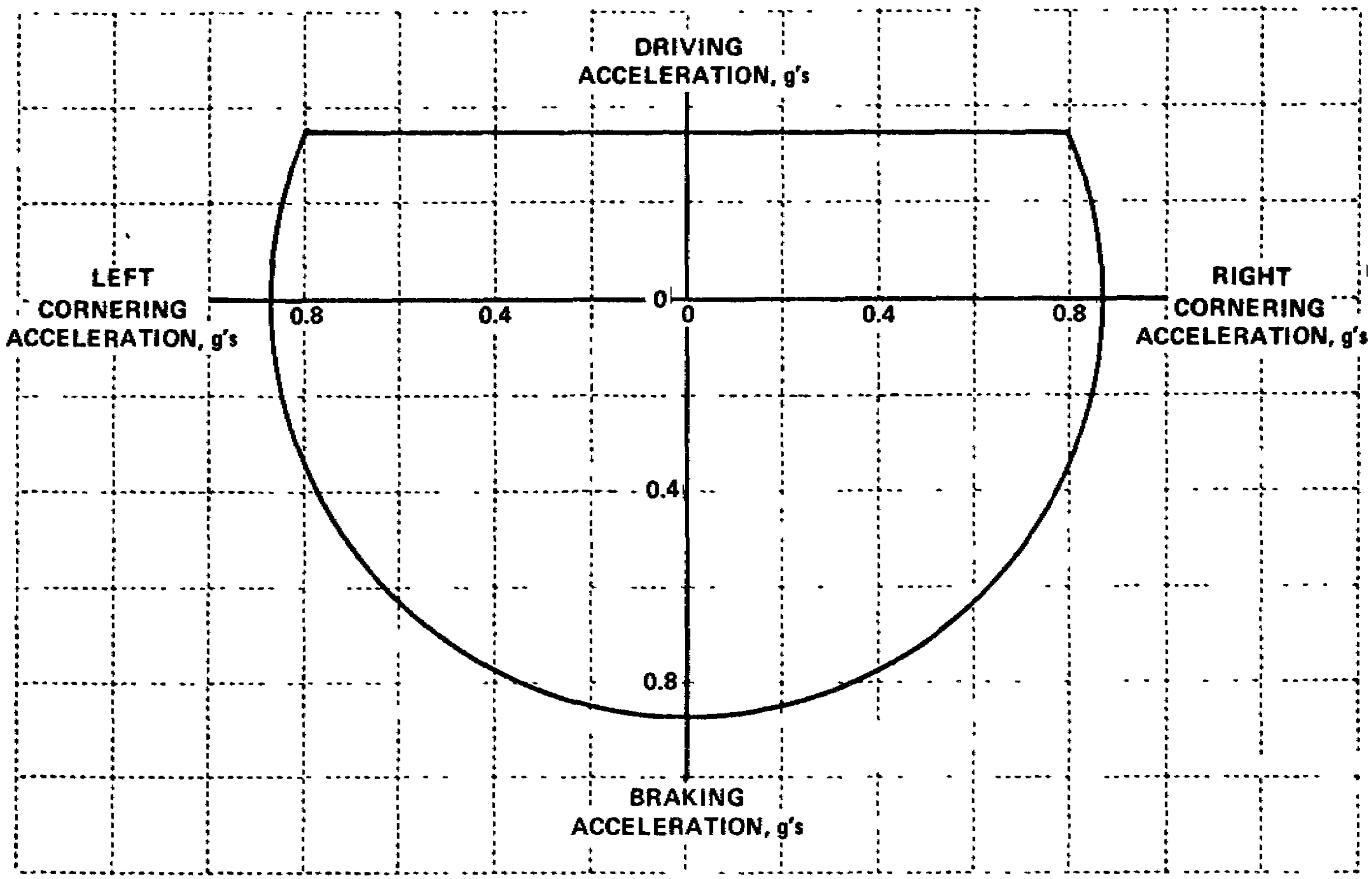


Figure 6-5 CAR PERFORMANCE LIMIT (IDEALIZED)

cornering acceleration used--values well within the acceleration envelope of the vehicle.

All the available evidence suggests that current domestic automobiles have accident avoidance characteristics that are at least satisfactory. Achievement of these characteristics, however, is realized through the careful tuning of interacting geometric and compliance features, many of which are nonlinear. Braking, handling, ride and stability are interconnected and manufacturers obtain their end results via individualistic routes (see Refs. 6-2 and 6-3 for example). There remains, then, the questions of (1) how the tentative RSV base vehicle (the C-6 Simca derivative) compares to current domestic vehicles, and (2) how weight for safety purposes might modify the behavior. Further, the candidate base vehicle is a front-engine, front-drive vehicle and, hence, differs in detail from the general domestic vehicle population.

In keeping with the priorities expressed in the introduction, conflicts between accident avoidance characteristics (weakly related to safety in accident data) on the one hand and occupant protection and fuel economy on the other are resolved by a heavy bias toward occupant protection and fuel economy.

Vehicle visibility is briefly summarized since, again, current vehicles are adequate in this respect--at least to the extent that such factors can be detected in accident causation.

Braking

The review of braking systems in the interim report showed that a substantial technical braking performance improvement could be effected by the introduction of a sophisticated anti-lock system. Mercedes-Benz has such a system at the present time and its main features are that (1) vehicle control can be maintained under all braking demands, and (2) stopping distance is less than that achievable with locked brakes under all road surface conditions. The high initial cost (currently about $400/vehicle) is not consistent with savings that could be generated in accident avoidance--estimated to be 4 to 8 percent of the cases in which locked wheels with subsequent maneuvering degradation contributed to observed accidents. Also, part of the braking performance of Mercedes' system may be attributable to vehicle tuning of weight transfer.

Domestic anti-lock systems improve skidding and/or steering under braking--but none of the domestic systems improve skidding, steering and braking performance simultaneously. Two additional factors enter:

- freedom from skidding and maintenance of maneuvering force capability are useless if the driver does not use the maneuvering margin

- driver action (braking pedal force application and pumping) can provide an improvement over locked-brake stopping distance without the installation of an anti-lock mechanical system.

Need and utility of anti-lock systems, then, are not general over the population and geography. They are properly classified as options and the following discussions are keyed to a base vehicle without an anti-lock system.

Braking System Redundancy

Current braking standards (FMVSS 105-75) require some degree of braking system redundance in order to minimize the possibility of the loss of all braking due to loss of a single operating component. Some of the possible configurations for accomplishing this purpose are shown in Figure 6-6 (from Ref. 6-2) for a relatively conventional sample vehicle. All the arrangements shown satisfy the braking standard. The degree to which the standard is exceeded is related to cost through additional material requirements and increased maintenance.

The tentative base vehicle uses the two-wheel system and it will be retained in the RSV variant because it is the minimum cost/minimum weight configuration consistent with current safety assessments.

Brake Capacity

The ability to pass the operable brake fade test (FMVSS 105-75) depends in part on the heat capacity and dissipation of the lining/drum combination. Structural modifications and occupant protection features of the RSV will increase the weight of the C-6 base vehicle and, hence, an increased brake capacity will be provided. This could be accomplished by inserting the Chrysler Dodge Dart front disc brake system and consequent increase in wheel disc size to 14" from the current 13" on the C-6.

Resultant braking performance of the C-6/RSV will be better than that on the heavier Dart. That is, the fully-operational-service-brake stopping distance will be less than 190 feet for all permissible loadings. Emergency operation (subsystem or brake power failure) will also satisfy FMVSS 105-75. A weight increment to the C-6 of about 50 lbs. may attend the larger brakes, wheels and tires. Relief from this weight penalty will be sought through use of stamped rotors, calipers in place of cast parts, and lightweight alloy wheels. Such substitutes are currently under development. Tires are discussed later in this presentation.

Brake Load Proportioning

Normal force division between front and rear tires is a function of deceleration since the c.g. of the vehicle is above the tire/ground contact

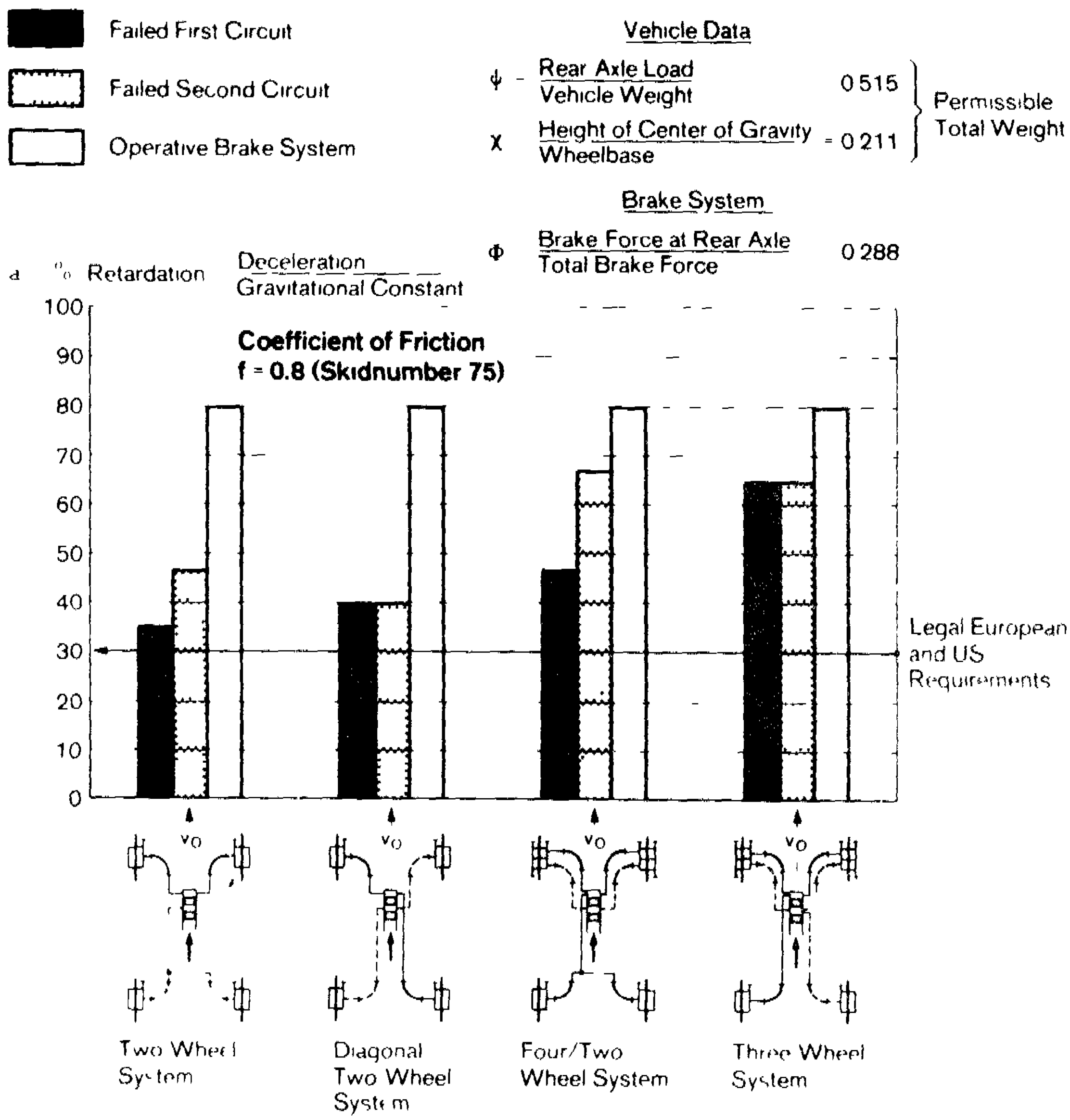


Figure 6-6 SPLIT BRAKING CONFIGURATIONS (REF. 6-2)

plane. Reaction of the inertial couple increases the normal force at the front and reduces that at the rear. The braking force should be similarly distributed, and many current cars have means for distributing braking pressure according to the dynamic load transfer. The C-6 has a front-rear split metering and load sensing proportioning system. It also has a larger wheel cylinder bore on the front than on the rear The front engine/front drive C-6 variant will have a front-to-rear weight ratio greater than 1.0* Current C-6 5-door models have 58% of the weight on the front and the RSV will show about 60% on the front. The basic weight distribution combined with the dynamic load transfer during longitudinal deceleration will place the braking burden on the front disc system--a desirable distribution from the vehicle stability standpoint.

Tires

A departure from current domestic practice with respect to the spare tire is planned in keeping with increased packaging efficiency and reduced cost. That is, only four wheels and tires are to be provided; but the tires will be one of the "run-flat" models which can be operated at reduced running speeds in the event tire pressure is lost. A possible interim substitute would be a "folded" spare (Ref. 6-5). Rapid advances in this area by the tire companies assure their timely productions (Refs. 6-5 and 6-6). Important advantages accrue:

- additional luggage space
- reduced cost
- convenience

---

* Front axle/rear axle ratios as low as 0.6 are reported for rear engine/rear drive vehicles and as high as 1.8 for front engine/front drive cars (Ref. 6-4). The basic C-6 ratio is about 1.4.

The particular tire being considered is presently under development by Goodyear and now being evaluated by Chrysler.

It is recognized that run-flat and multiple-cell tires were being operated on a trial basis in the late 1950's--see, e.g., Ref. 6-7. Elimination of the spare was hardly a critical item in the years from 1960 to the present in view of the growth of car size. Projected consumer interest in greater packaging efficiency--i.e., the RSV--makes the elimination of the spare tire a timely item again.

Detailed carpet plots of tire force characteristics are not immediately available for the run-flat. Therefore, some elements of the tire trade-off remain to be made before the selection is made final--namely, the rolling resistance and cornering forces. Rolling resistance of the tire influences fuel economy and it is known that some advantages accrue to the radial tire on this count (compared to other current construction (Ref. 6-8)), at road speeds less than 80 MPH. Data are being sought on the run-flat designs. The Goodyear Tire and Rubber Company has informed Chrysler Corporation that their version can be made with any of the current lays including radial. Tire properties are provided in Section 6.3.

Braking and cornering forces developed by tires are also functions of construction and materials. However, a study conducted at Calspan indicates that vehicle characteristics* tend to dominate the overall performance so that differences between tires exhibited on tire testing machines are almost washed out in vehicle tests (Refs. 6-9 and 6-10). Figure 6-7 from

* It is necessary to qualify the results by noting that the tests were conducted with 1971 model cars that had no braking proportioning provisions.

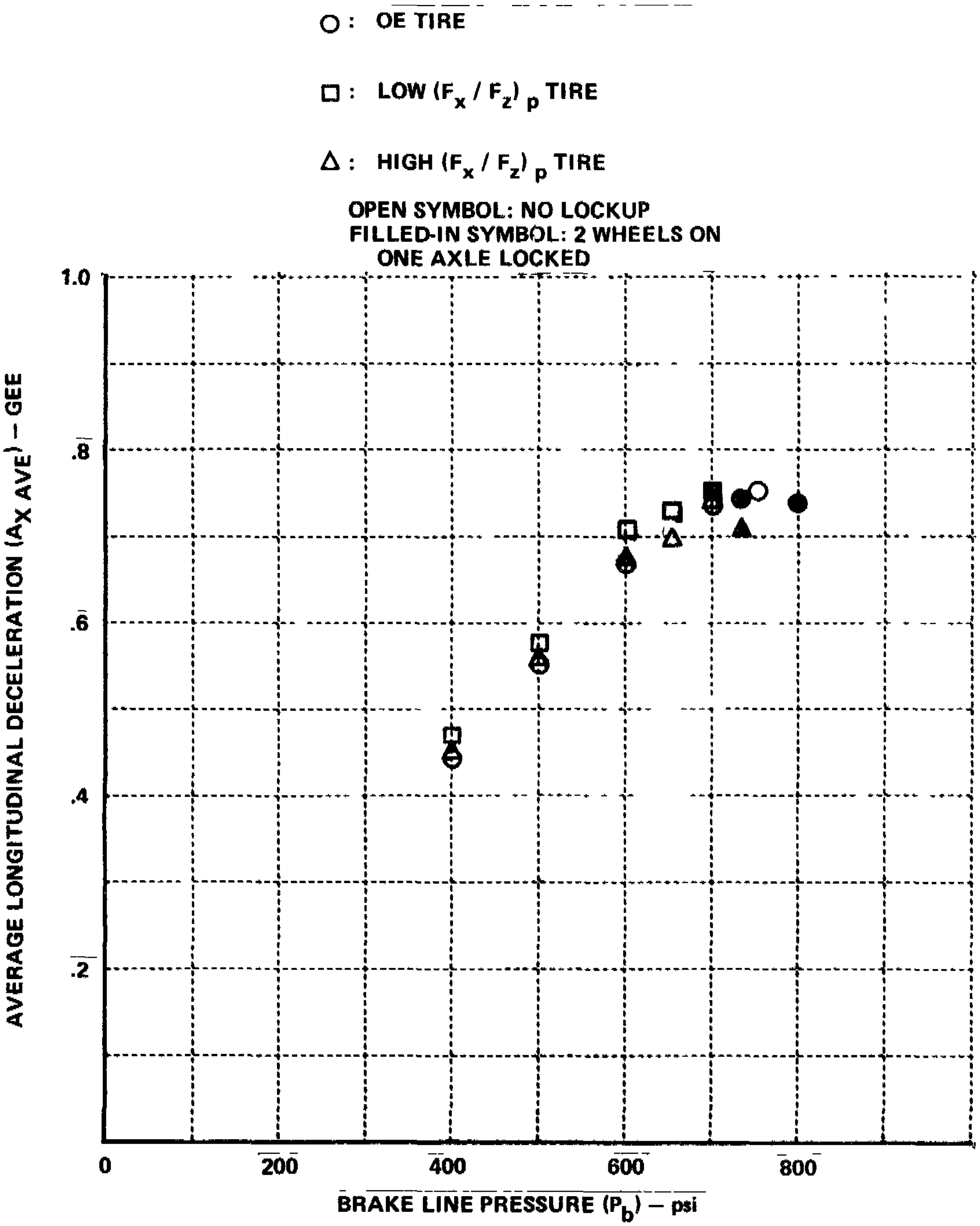


Figure 6-7 BROOKWOOD (1971) IN STRAIGHT BRAKING TEST

Ref. 6-10 shows some of the straight braking results for tires which had peak longitudinal friction coefficients $(F_x/F_z)^*$ ranging from about 0.9 to 1 1.

It is anticipated that the run-flat tires would not degrade significantly the braking and cornering of the modified C-6.

Parking Brake

The modified C-6 parking brake, operating on the rear drum brakes, will satisfy the 30 percent grade requirement of FMVSS 105-75. Required indicator lamps would be installed.

Steering

U. S. domestic vehicles are understeer and the RSV should retain this characteristic. Chrysler Corporation cars have steering capabilities judged to be good by the U. S. driving population. These are compared with the estimated responses of the C-6 and discussed in the light of recent hypotheses about desirable steering responses.

Figures 6-8 and 6-9 show the calculated yaw responses of the compact Chrysler line and Figures 6-10 and 6-11 corresponding calculations for the standard size cars. The following are noted:

- the degree of understeer is near the maximum suggested in the RSV tentative specifications

---

* F_x = Decelerating Force

F_z = Normal Force

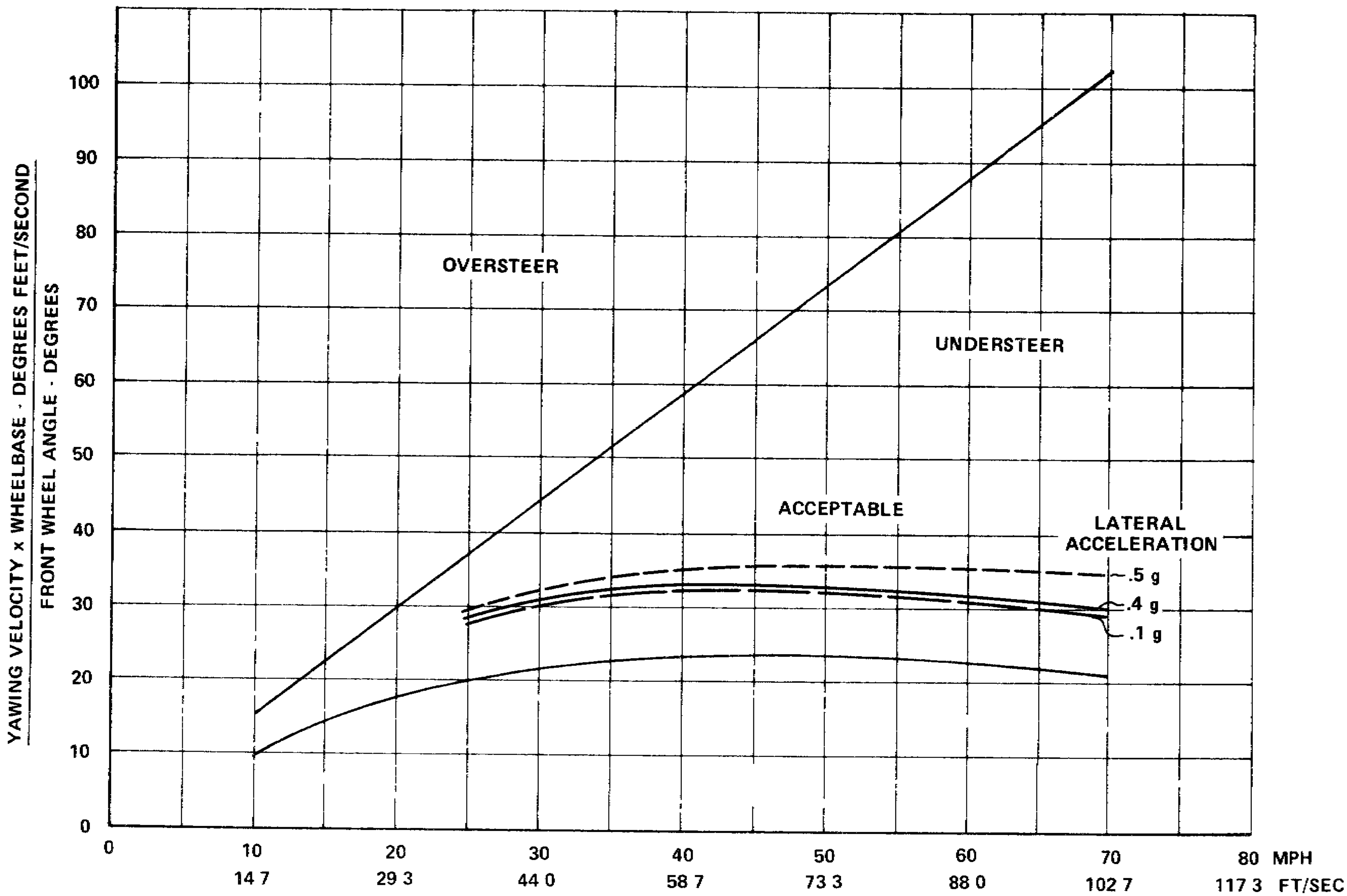


Figure 6-8 STEADY STATE YAW RESPONSE VERSUS TANGENTIAL VELOCITY, CHRYSLER COMPACT

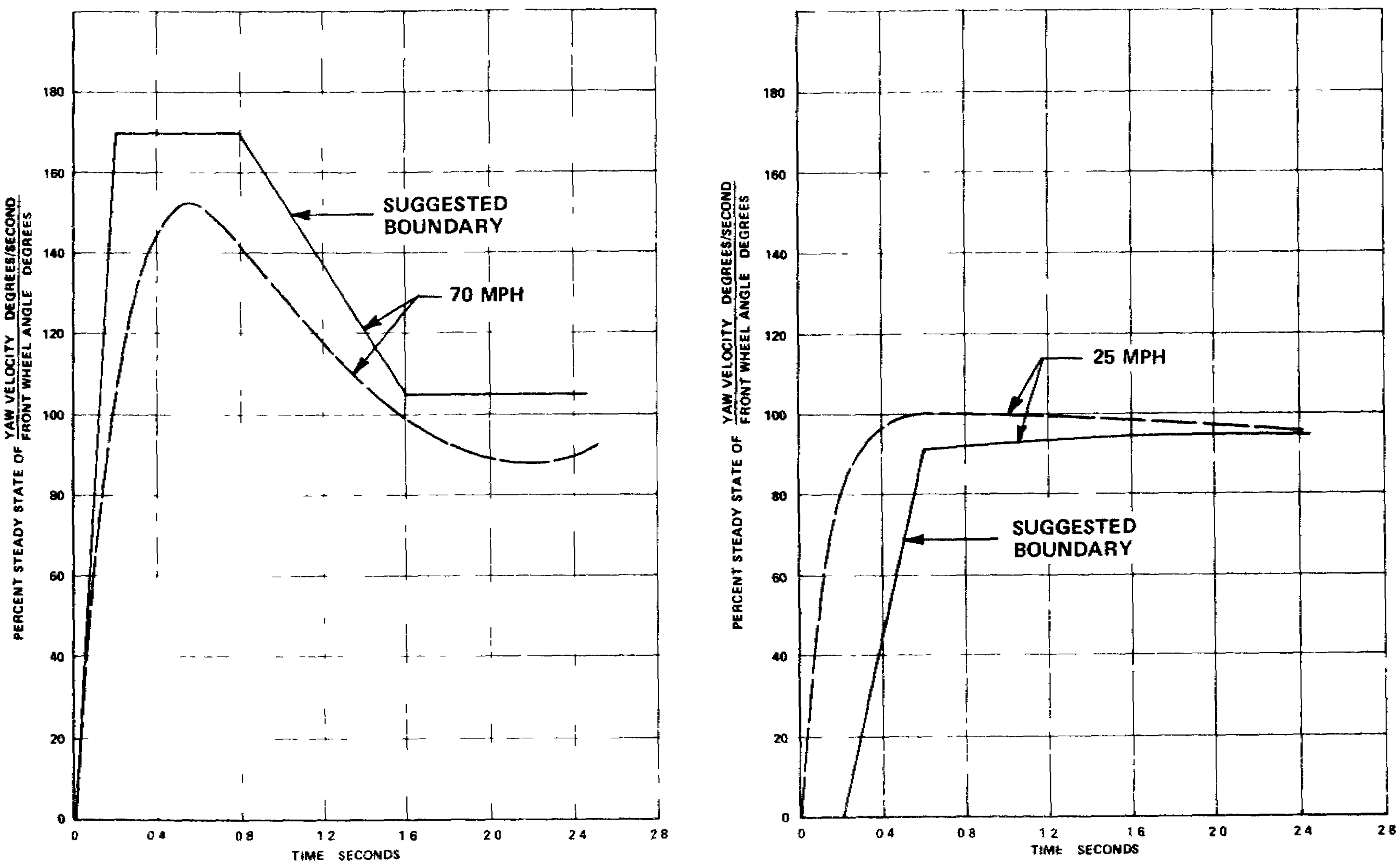


Figure 6-9 TRANSIENT YAW RESPONSE VERSUS TIME, CHRYSLER COMPACT

- the degree of understeer is nearly independent of lateral acceleration

- the yaw response time at 70 MPH is very short (e.g., the time of first crossing of the final steady-state in the transient)

- the yaw damping at 70 MPH is within the suggested envelope

Recall, again, that these vehicles have steering characteristics believed to be good by the driving public.

Corresponding calculations for the C-6 are shown in Figures 6-12 and 6-13. This front-engine, front-drive vehicle shows estimated steady yaw characteristics similar to those presented for the Chrysler domestic vehicles except that the degree of understeer increases noticeably with lateral acceleration. The transient yaw response is slightly less damped but the response time is correspondingly shorter. It was previously noted that the steer characteristics can be varied by tuning. For example, addition of a stiffened rear swaybar to the C-6 produces steering characteristics shown on Figures 6-14 and 6-15. These are very close to those obtained with the domestic models.

All the transient responses presented above showed yaw damping comparable to the ESV specifications and the tentative RSV specifications. The domestic vehicles have evolved over a long time period and are judged to be well behaved by the consumer. However, it has been suggested that the transient envelope is not a precise measure of desirable steering characteristics--a matter developed in discussions by ESV contractors (e.g., Refs. 6-11 and 6-12). Continuing effort at Volkswagen--initiated during their ESV program--has indicated that subjective ranking of steering responses

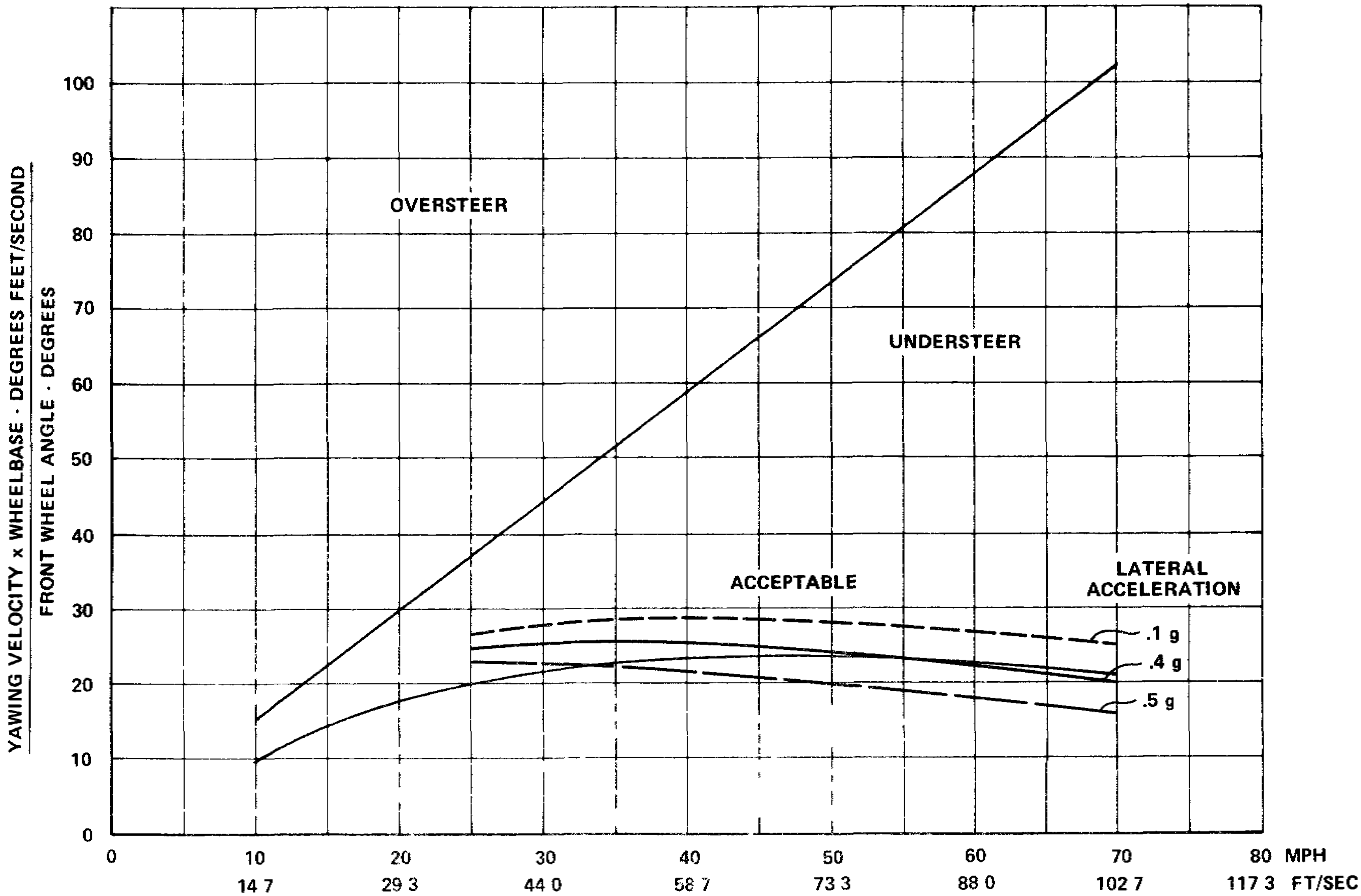


Figure 6-12 STEADY STATE YAW RESPONSE VERSUS TANGENTIAL VELOCITY, C 6

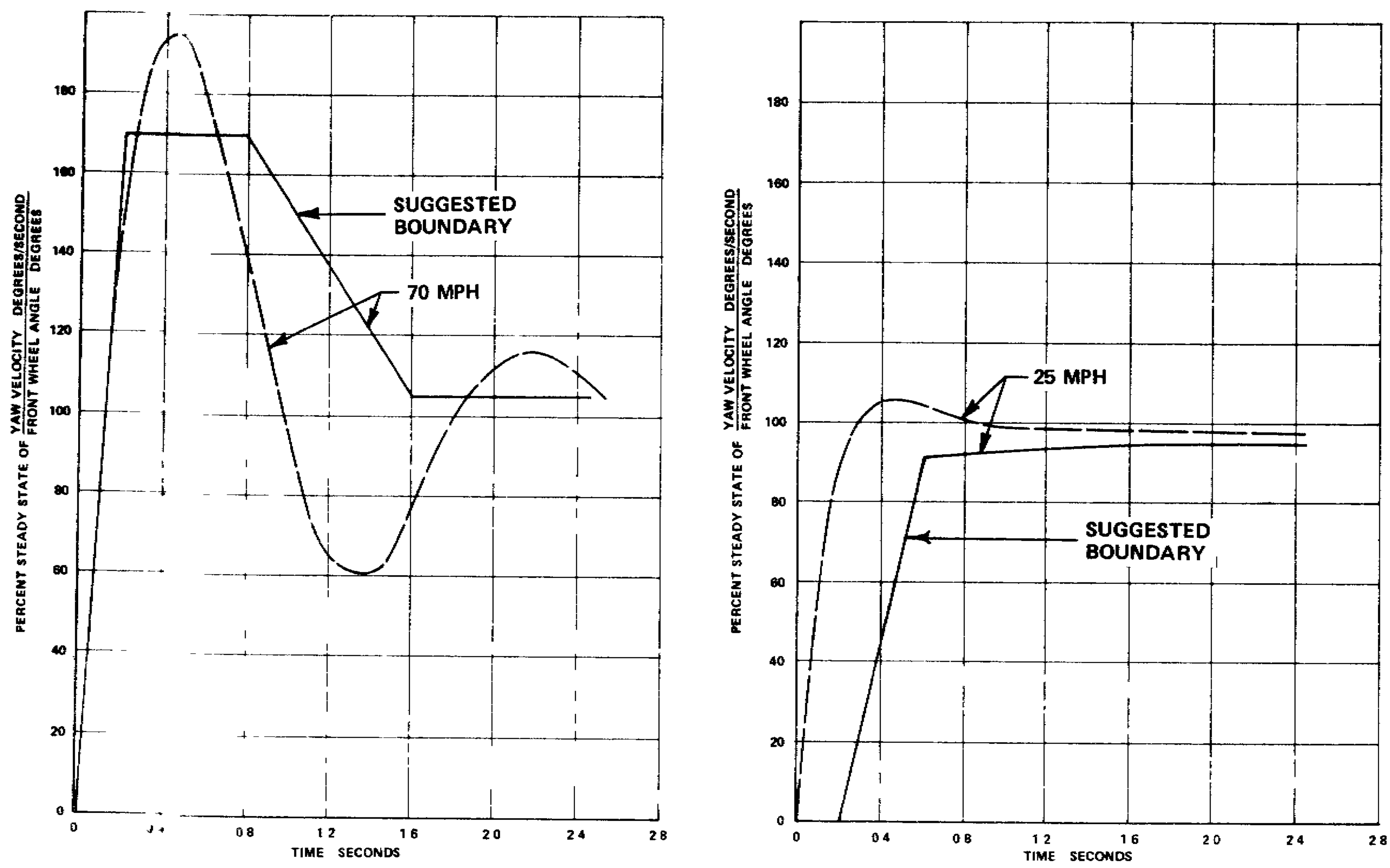


Figure 6-13 TRANSIENT YAW RESPONSE VERSUS TIME, C-6

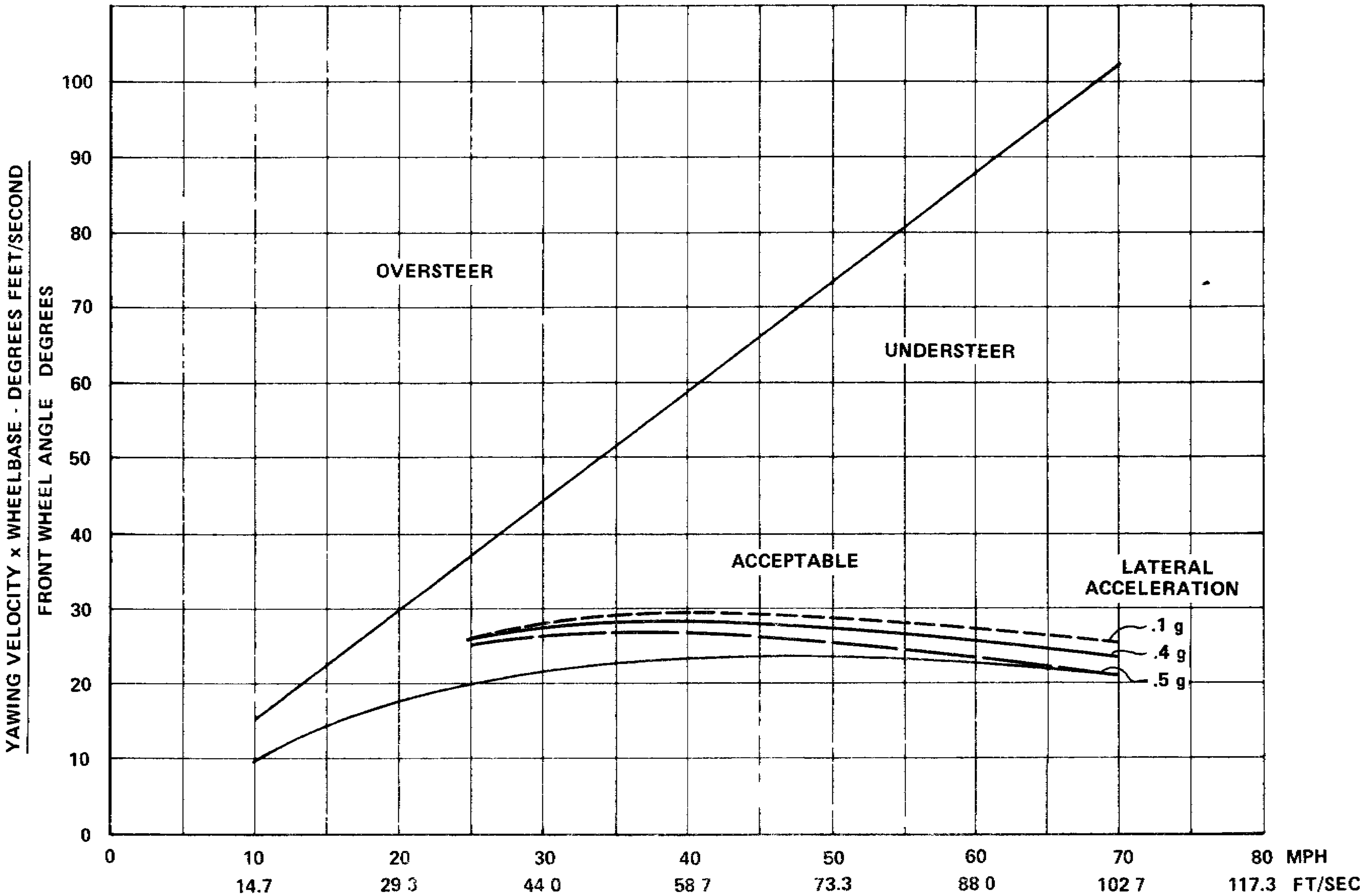


Figure 6-14 STEADY STATE YAW RESPONSE VERSUS TANGENTIAL VELOCITY, C-6 STIFFENED SWAYBAR

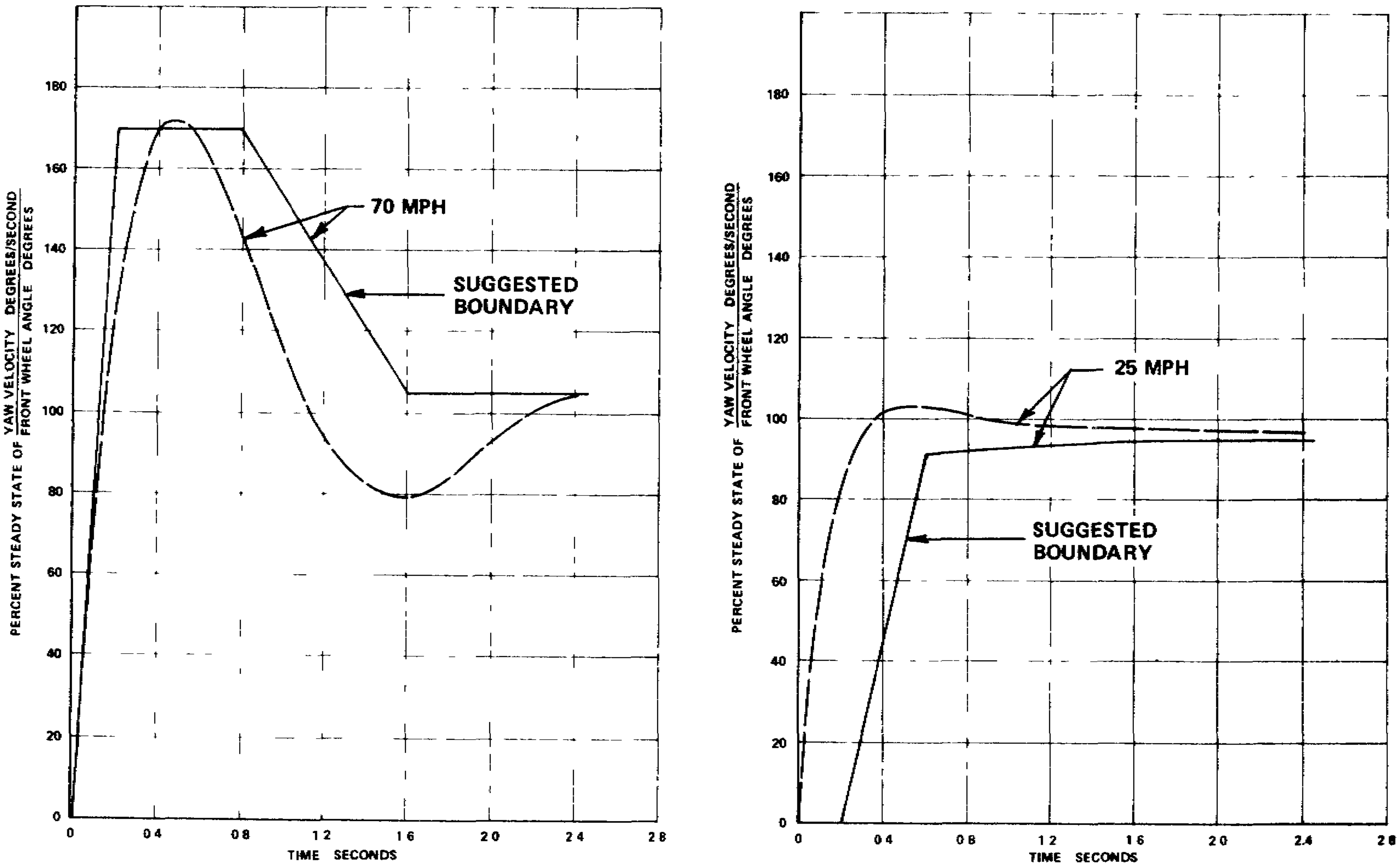


Figure 6-15 TRANSIENT YAW RESPONSE VERSUS TIME, C-6 STIFFENED SWAYBAR

may correlate more readily with the product of yaw rate response time and steady-state sideslip angle than with the yaw transient envelope (e.g., Refs. 6-13 and 6-14). We are inclined to believe that the rapid steering response of the C-6 will offset its reduced damping. Further, increasing the damping may compromise steering returnability at low speeds (as noted by G.M. in explaining an ESV non-compliance in Ref. 6-15). This matter of the response time vs. the transient envelope is important because structural changes in the C-6 to provide greater frontal and lateral crashworthiness will increase the yawing inertia and, hence, the yaw response time. Longer wheelbase will partly offset this effect.

Steering returnability is a function of the steering aligning torques, damping and coulomb friction in the kingpins and linkages. It was noted above that dissipation (damping) is necessary to provide a damped yaw transient. Concentration of the dissipation function in coulomb components can result in a band of possible final steady-state headings after release of a steering input. General Motors found that its ESV was deficient in this regard with respect to ESV specifications; but noted that drivers did not find this deficiency troublesome (Ref. 6-15). It is anticipated that the modified C-6 will be satisfactory with respect to steering returnability.

Handling: Control at Breakaway and Directional Stability

Maintaining control and regaining the proper traffic lane after having entered a curve at too great a speed and breaking away are safety-related tasks. Vehicle behavior and proper recovery steering inputs by the driver are functions of the oversteer/understeer characteristics and the manner in which the limit of control is approached.

The C-6 is basically understeer as previously noted. Furthermore, it is "power understeer"--that is, as tractive forces are applied to increase speed in a constant radius turn, the vehicle tends to become more understeer.

At breakaway then, the vehicle will maintain its understeer characteristic and become a "plower" as front wheel adhesion is lost. Subsequent release of the throttle produces a conventional steering input to return to the initial path and the vehicle will be judged to be well behaved.

The above desirable control characteristics obtained at the limit of control are not realized without some "penalty". Any steer characteristic other than neutral (i.e., either understeer or oversteer) detracts from the maximum steady-state lateral acceleration that can be reached simply because all tire forces do not saturate at the same time--therefore, the maximum potential of side force is not achieved. Current practice--in which all manufacturers concur with respect to vehicles sold to the general public--is to accept this loss in cornering performance in favor of the desired stability characteristic; and this practice will be continued on the candidate RSV as noted above.

Directional stability of the modified C-6 should be in keeping with the current state-of-the-art. That is, responses to wind and road disturbances will create aligning forces tending to return the front-drive vehicle to its initial trajectory. The C-6 is satisfactory in this regard and the proposed modifications should produce an enhanced wind response because the aerodynamic center will be farther behind the center of gravity.

Directional response to road inputs and steering torque cues afforded the driver will be similar to the C-6 and should be satisfactory.

Overturning Immunity

The C-6 tread width, c.g. location, and tire adhesion limits make overturning very unlikely without an obstacle contact. Projected increases in width of the modified version will improve this stability and offset a possible slight increase in c.g. height.

Visibility from the Vehicle

Visibility from the C-6 is in line with current standards. Any direct marketing in the U. S. would impose 1975 Federal visibility rules and the vehicle would, of course, satisfy these. Strengthening of the compartment in the modified (RSV) version may result in an increase in the B-pillar width (see Section 6-3)--but this would have a minimal effect on visibility. Increasing the compartment height in the modified version would be accompanied by improved vision for the more upright occupants. These and other factors (such as defog, defrost systems) were discussed at greater length in Volume III.

Visibility of the Vehicle

It is unlikely that strong restrictions can or should be mandated on vehicle color in the domestic market. Nevertheless, the prototype RSV should be a light colored vehicle and color contrasting strips should be incorporated in the protective trim (rub strips). Location of turn signal lamps at places removed from other lights would be sought. Again, background data on vehicle visibility was developed in Volume III.

6.2.4 Base Vehicle Crash Performance

The vehicle selected for the RSV, the C-6, is an evolutionary derivative of the Simca which is also made by Chrysler France. Therefore, the production Simca, shown in Figure 6-16 is a good approximation to the tentative RSV base vehicle and as such was examined from a crashworthiness viewpoint to determine the degree to which it satisfies the desired RSV crash performance criteria.

Considerable frontal structure test data are currently available for the Simca. Nominal 30 MPH flat barrier frontal impact test data are available from a Calspan test. The Calspan test (Refs. 6-16 and 6-17) was a U. S. Department of Transportation sponsored compliance test for which occupant

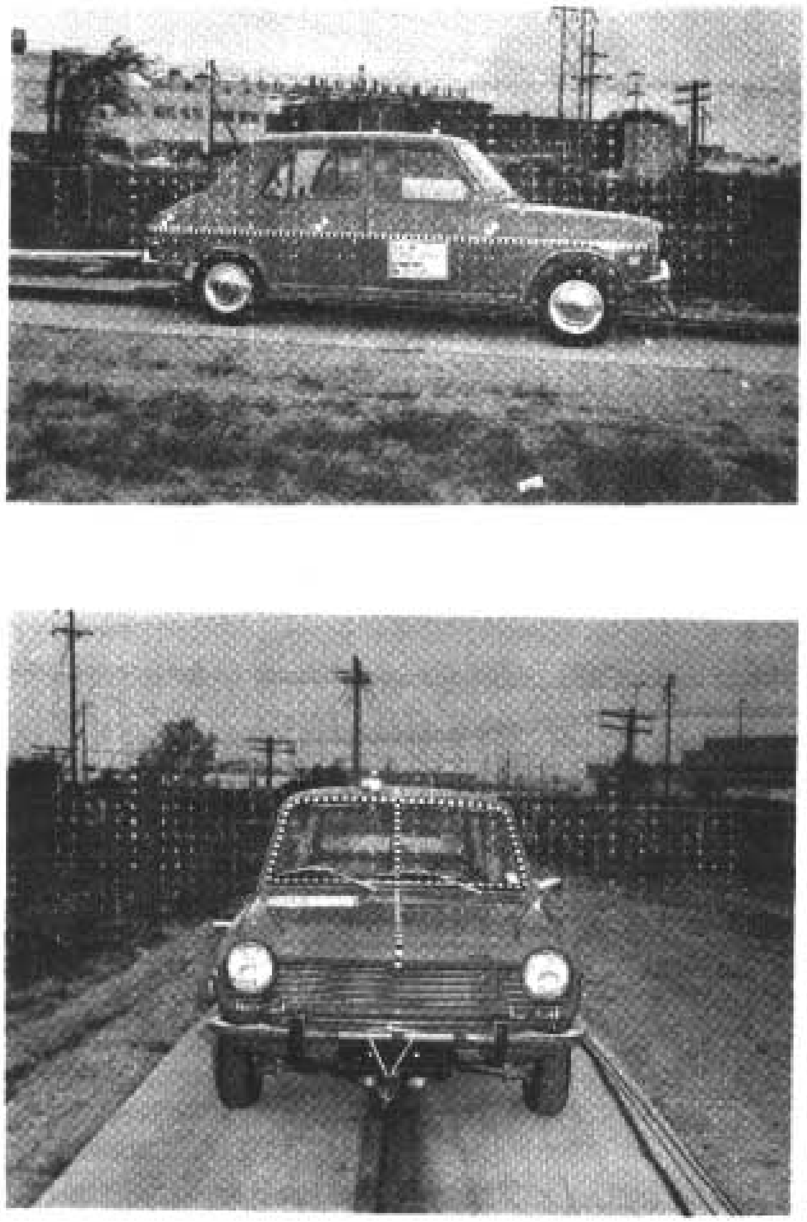


Figure 6-16 1971 SIMCA 1204

compartment accelerations were measured. In addition, static crush test data are available from a crush test conducted on the Simca in the Calspan crush test facility for the Chrysler Corporation. The static crush test data have been used as inputs to a crash simulation computer model, BASHSIM, which predicts vehicle dynamic crash test performance based on static force deflection properties of major structural components of a specific automobile.

BASHSIM is a Chrysler Corporation developed computer simulation of an automobile consisting of eight springs and three masses as shown in Figure 6-17. Using static crush data to define the force deflection properties of the eight springs in the model, dynamic crash tests of the automobile can then be simulated. Used as a design tool, this combination of limited experimental data and simplified vehicle structural model can be used to investigate design changes for a fraction of the cost of actual crash tests.

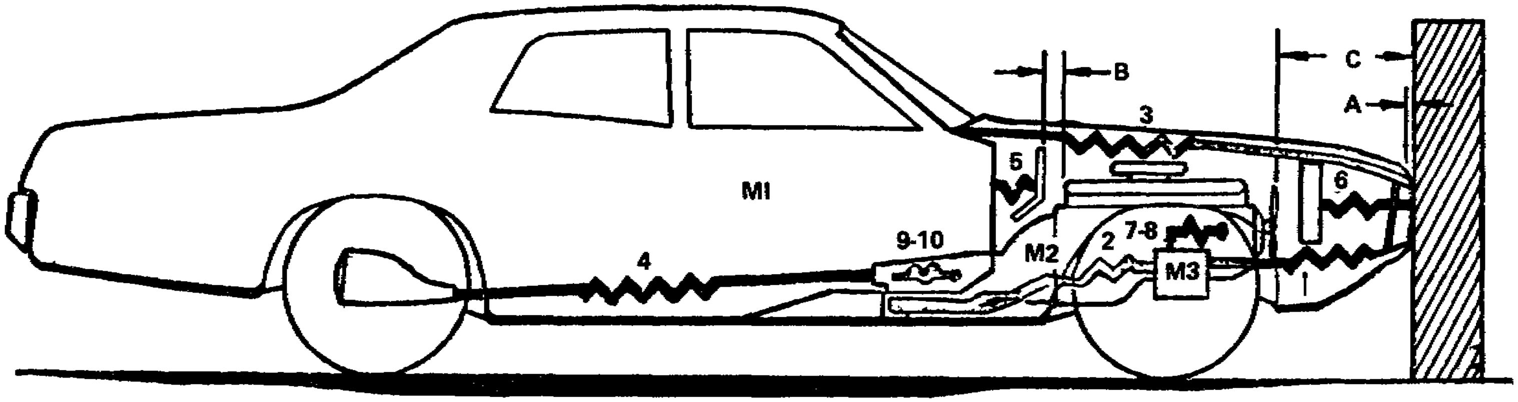
To establish confidence in the model and to develop competence in applying the static crush test results, the simulation program was run using the test data shown in Figure 6-18. The static crush test data were generated by crushing a Simca 1100 in the Calspan Corporation Crush Test Facility. As is apparent from Figure 6-18, six different static tests were performed to develop the force-deflection data. Typical crush test setup and fixturing are presented in the photographs of Figure 6-19. The various masses and dimensions appropriate to the Simca were also inputted to the program. These are listed in Table 6-4 where masses and dimensions correspond to those shown in the schematic illustrations of Figure 6-17. Comparisons between the 30 MPH crash test and the 30 MPH simulation

Table 6-4

INPUT FOR BASHSIM SIMULATION OF SIMCA 1100

MASSES*		DIMENSIONS*	
M1	1870	A	3.7
M2	200	B	7
M3	180	C	17.6

* SEE FIGURE 6-17 FOR DEFINITION



MASSES

M1	–	TOTAL CAR LESS M2 AND M3
M2	–	ENGINE AND TRANSMISSION
M3	–	FRONT CROSSMEMBER, SUSPENSION, TIRES, AND WHEELS
1	–	FRONT OF RAILS
2	–	REAR OF RAILS
3	–	FRONT SHEET METAL
4	–	DRIVELINE
5	–	DASH
6	–	RADIATOR
7	–	ENGINE MOUNTS - FWD.
8	–	ENGINE MOUNTS - RWD.
9	–	TRANS. MOUNTS - FWD.
10	–	TRANS. MOUNTS - RWD.

DIMENSIONS

A	–	FRONT SHEET METAL TO BARRIER
B	–	REAR OF ENGINE TO DASH PANEL
C	–	FRONT OF ENGINE TO BARRIER

Figure 6-17 SCHEMATIC OF BASHSIM MODEL

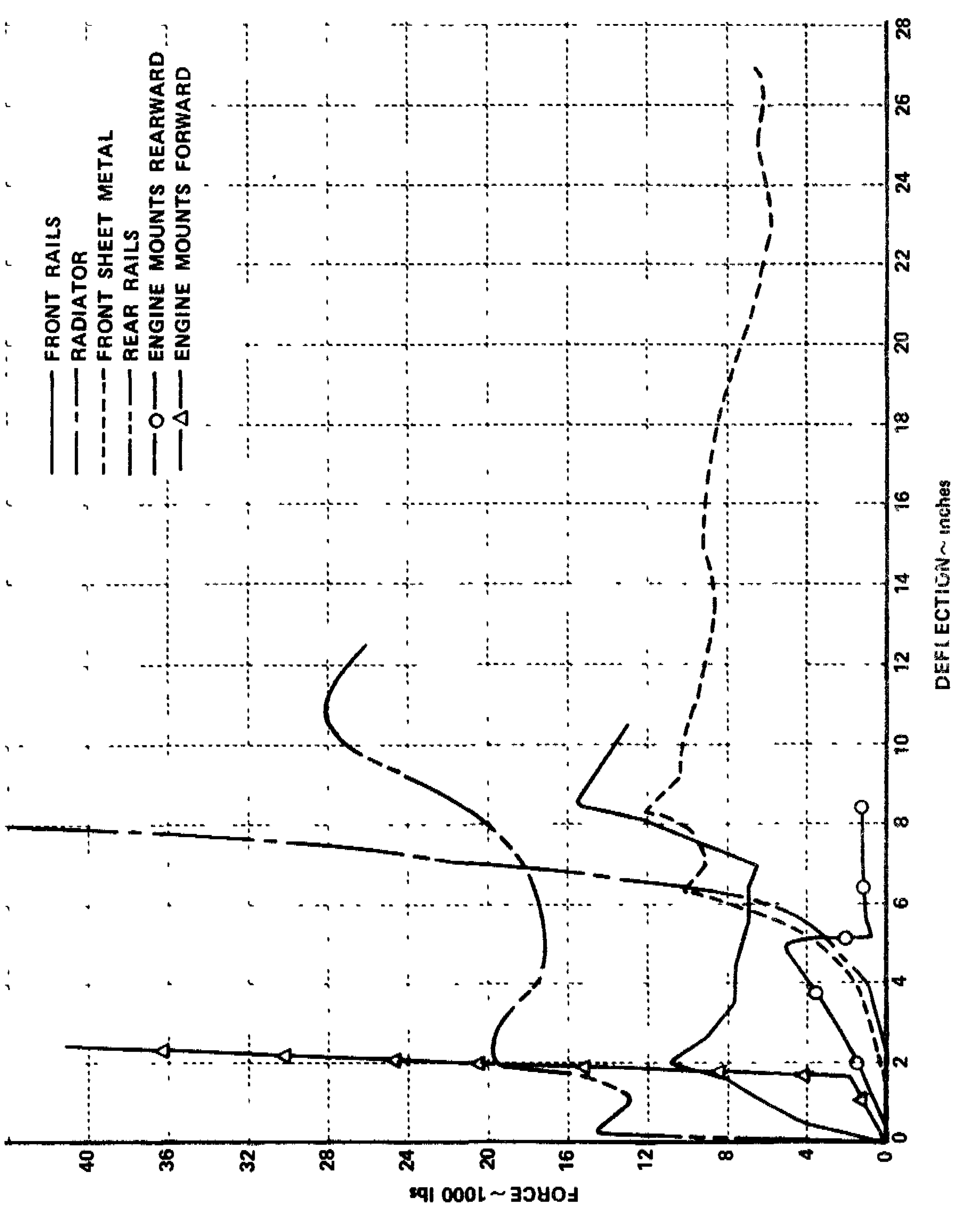
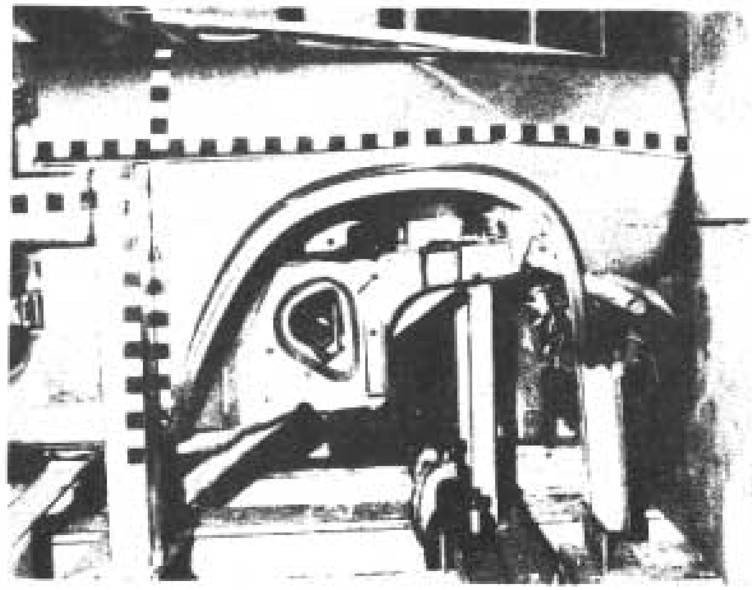
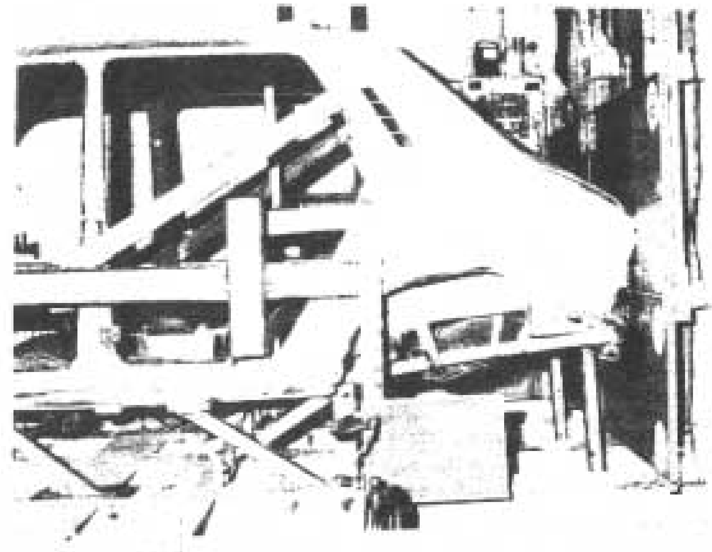


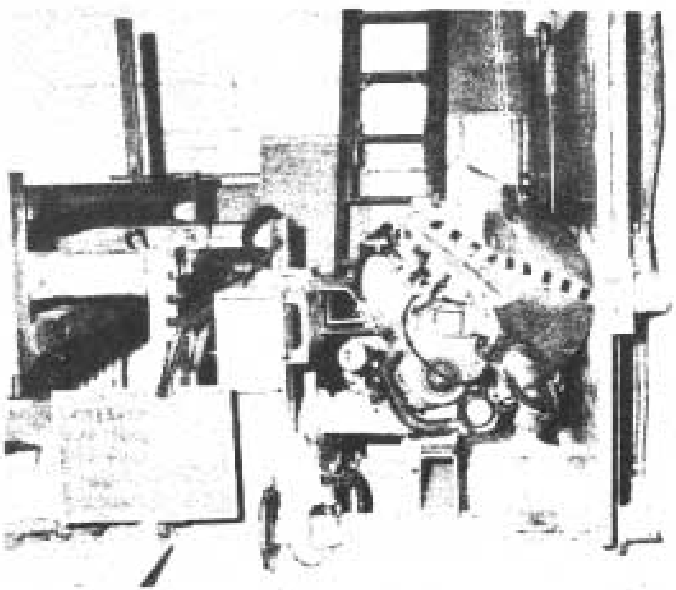
Figure 6-18 COMPONENT FORCE DEFLECTION DATA FOR SIMCA 1100



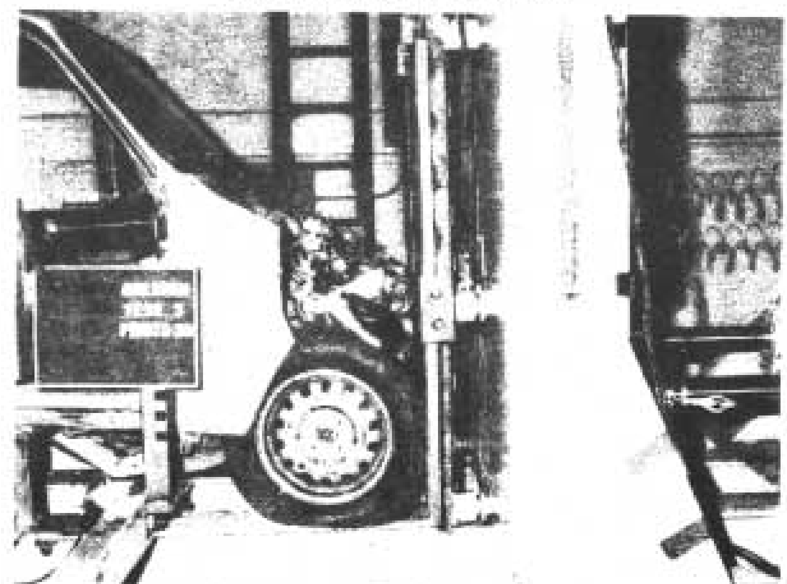
a. FRONT END SHEET METAL



b. REAR END SHEET METAL



c. RADIATOR INTO ENGINE



d. REAR OF FRONT RAILS

Figure 6-19 SIMCA STATIC CRUSH TESTS

are given in Figures 6-20 and 6-21, which are time and displacement histories, respectively, for the occupant compartment. The agreement between model and experimental results exhibited in Figures 6-20 and 6-21 is very good, demonstrating that it is valid to use the model to investigate structural modifications as discussed in Section 6.3.

Post-crash photographs of the Simca used in the Calspan test are included in Figure 6-22 to indicate the amount of structural deformation experienced by the vehicle in a 30 MPH barrier test.

Included in Figure 6-21 are cross-hatched areas which represent the displacement and acceleration bounds specified in Volume III of this report as the desired ranges in these crash characteristics for the RSV frontal structure. Comparing the Simca experimental results with the indicated desired ranges in Figure 6-21 illustrates the degree to which the deceleration pulse must be modified to produce the desired RSV front structure crash behavior. Zone I_f, the first six inches of the vehicle, does not exist on the base vehicle inasmuch as this zone is the bumper region which will be an add-on section to the base vehicle as discussed in Section 6.3.4 and also later in this section. Zone II_f, which is the region from about 4 to 16 inches, will need some strengthening to achieve a higher stroke efficiency. Note that the plateau in the acceleration curve at around 11-14 inches in Figure 6-21 for the production Simca is about 20 g as desired for side impact compatibility. However, from 6 to 10 inches of displacement, the vehicle structure is insufficient to produce the 15-20 g deceleration required and would need to be improved. Zone III_f, the high speed frontal impact protection region extending from the end of Zone II_f to approximately 36 inches, is seen to require substantial change to bring the production vehicle crash performance in line with the RSV design goals.

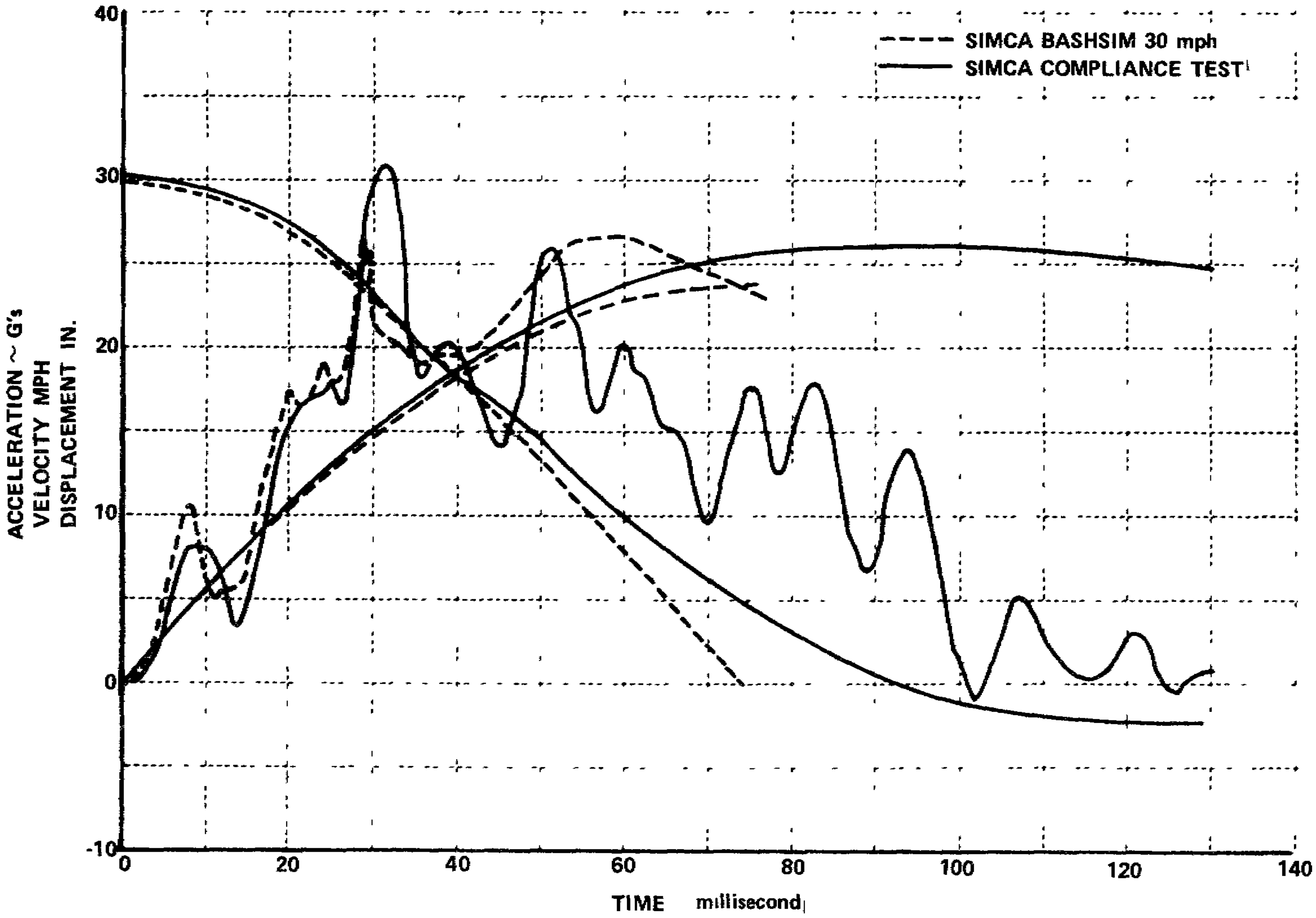


Figure 6-20 COMPARISON OF BASHIM SIMULATION RESULTS WITH CRASH TEST DATA FOR 30 MPH FRONTAL BARRIER IMPACT OF 1971 SIMCA

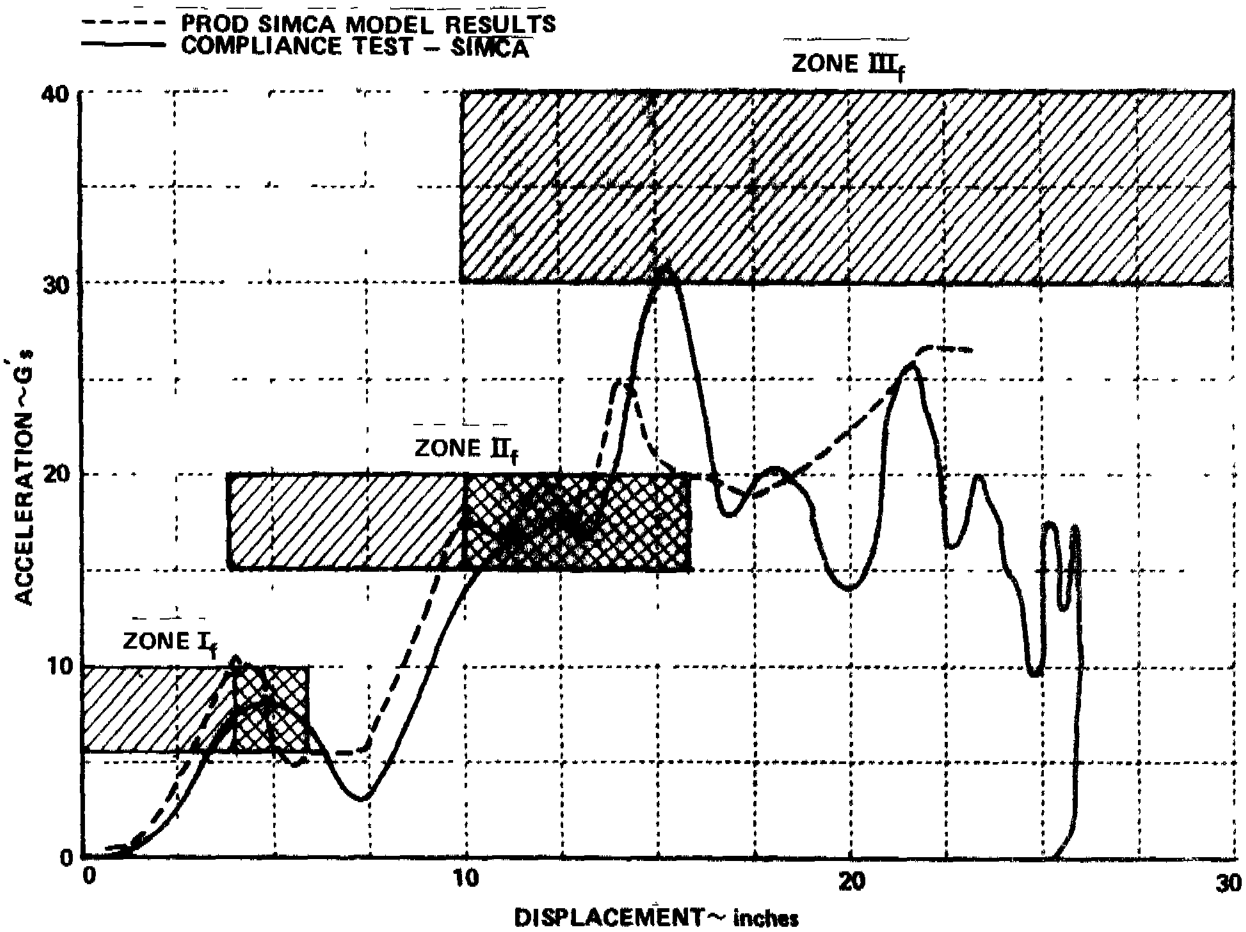


Figure 6-21 COMPARISON OF DECELERATION-DISPLACEMENT HISTORIES FROM A CRASH TEST AND A BASHSIM COMPUTER SIMULATION FOR A PRODUCTION SIMCA 1204 FRONTAL BARRIER IMPACT

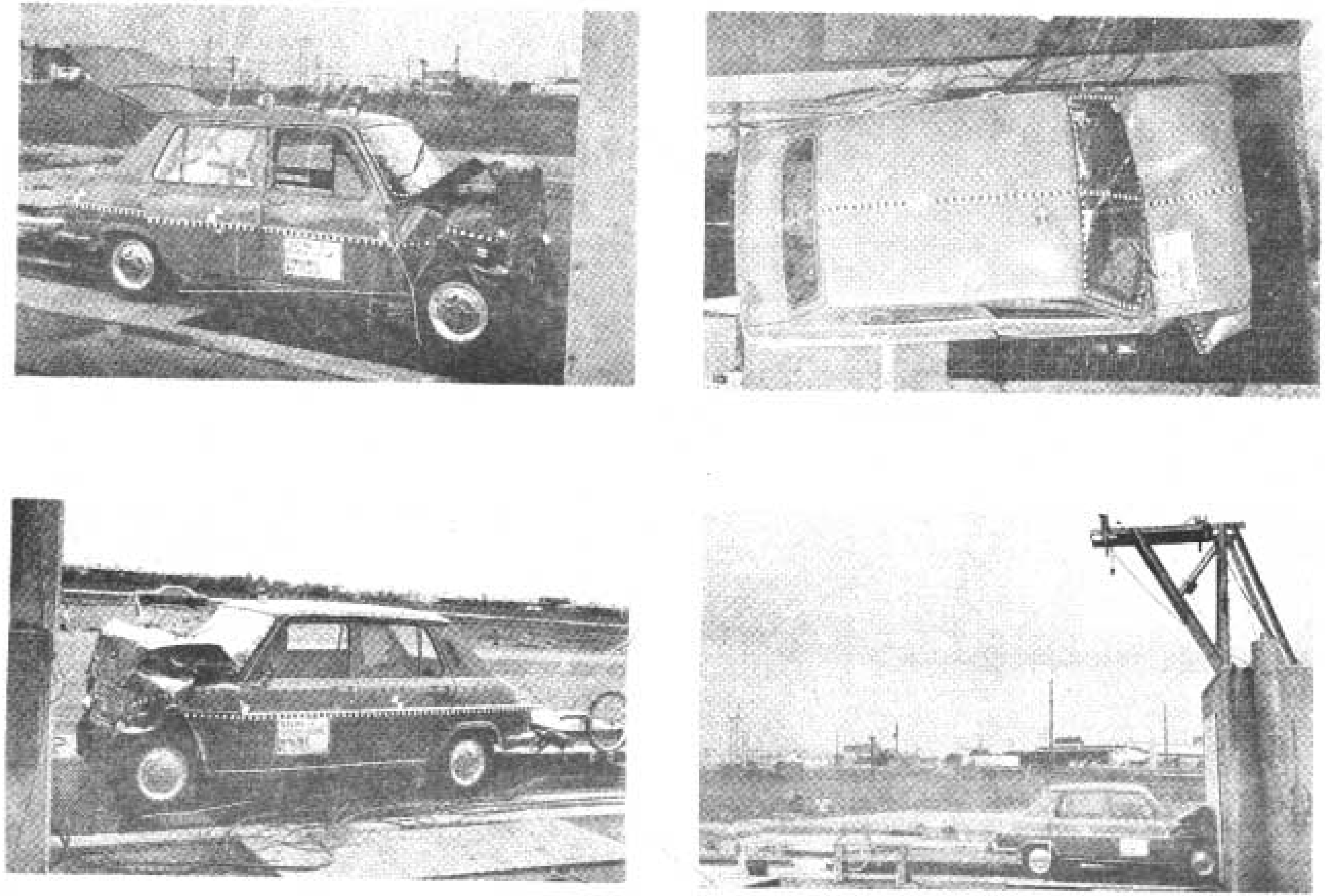
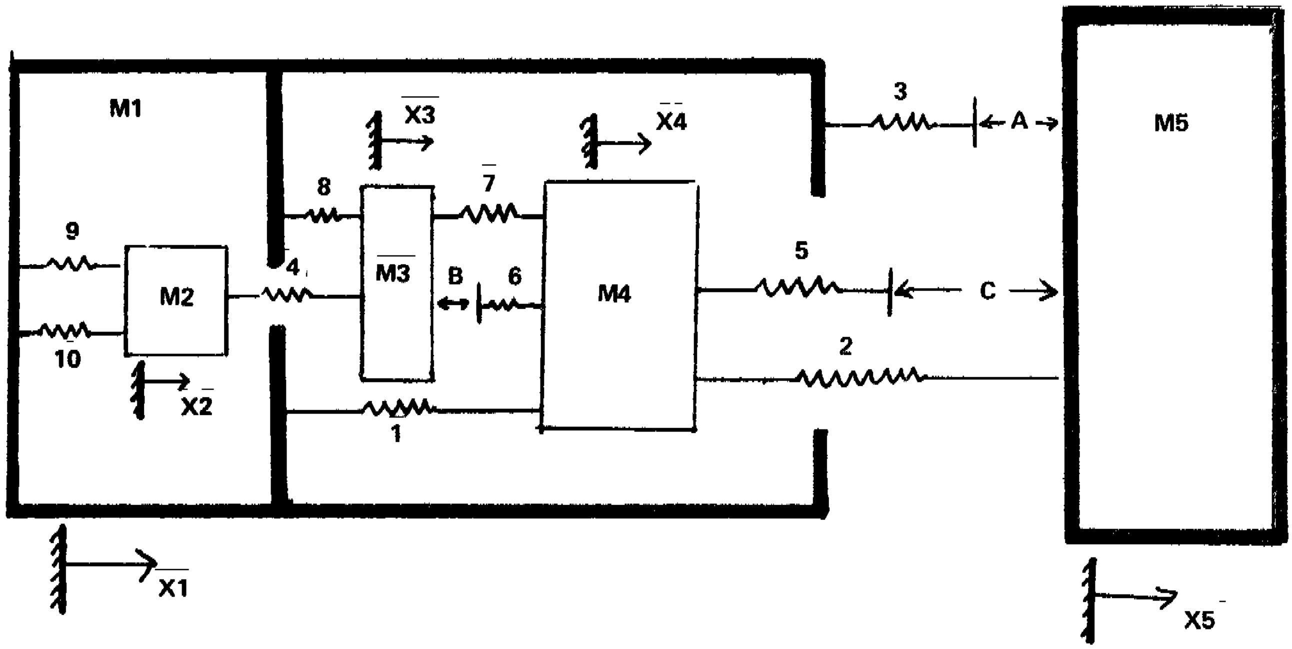


Figure 6-22 POST-CRASH PHOTOGRAPHS – 1971 SIMCA 1204

Although detailed crush test data for the Simca in rear barrier impacts was not available in time to be included in this report, a computer simulation of such a test configuration was made to assess the need for rear structure changes in the base vehicle. This simulation was carried out using rear static crush test data in another Chrysler Corporation computer model called REARIMP which is the rear end counterpart of BASHSIM which has already been shown to accurately predict crash test results. REARIMP consists of five masses and ten springs as defined in Figure 6-23.

REARIMP was exercised, using rear structure static crush test data generated in The Calspan Corporation Static Crush Test Facility, for a 30 MPH fixed barrier rear end collision. The results of the simulation are shown in Figure 6-24 which indicates the compartment acceleration, velocity and displacement time histories. These results indicate that the base vehicle rear end structure should require no modification to meet RSV specifications; namely, a 12-25 g acceleration range over 20-26 inches of crush which corresponds to a dissipated crash energy of 70,000 to 95,000 ft-lbs. for a 3000 lb. vehicle. In addition, although the results presented here do not indicate it, the rear structure of the base vehicle stiffens appreciably at crush distances around 28 inches which would force more of the vehicle deformation into Zone II_f of the impacting vehicle in a car-to-car rear end collision at speeds appreciably greater than 50 MPH, which is approximately the equal mass car-to-car equivalent of 30 MPH single vehicle into a fixed barrier.

Preliminary studies of possible structural modifications to the base vehicle to achieve the structural crashworthiness goals desired for the RSV are included in Section 6.3. These studies address not only the frontal impact crashworthiness but also side, rollover, and rear impact. For the front structure studies, the computer simulation model was exercised to determine the approximate magnitude of the structural strength changes needed to achieve the desired crash performance. As has been shown here, the basic rear structure is adequate in the base vehicle and will require no major modification. Concern in the rear structure will be primarily limited to minimizing low speed impact vehicle damage and maintaining fuel system integrity in higher speed impacts.



MASSES	RESISTANCES		CRUSH
M1 - Total car less (M2 + M3 + M4)	1	Frt. of rr. rail	X1-X4
M2 - Engine and transmission	2	Rr. of rr. rail	X4-X5
M3 - Rr. axle	3	Rr. sheet metal	X1-X5-A
M4 - Gas tank	4	Driveline	X2-X3
M5 - Barrier	5	Rr. of gas tank	X4-X5-C
	6	Frt. of gas tank	X3-X4-B
	7	Rr. of leaf spring	X3-X4
	8	Frt. of leaf spring	X1-X3
	9	Engine mount	X1-X2
	10	Transmission	X1-X2

CLEARANCES

A - Rr. sheet metal to barrier
B - Gas tank to differential
C - Gas tank to barrier

Figure 6-23 SCHEMATIC OF REAR IMPACT (REARIMP) COMPUTER SIMULATION MODEL

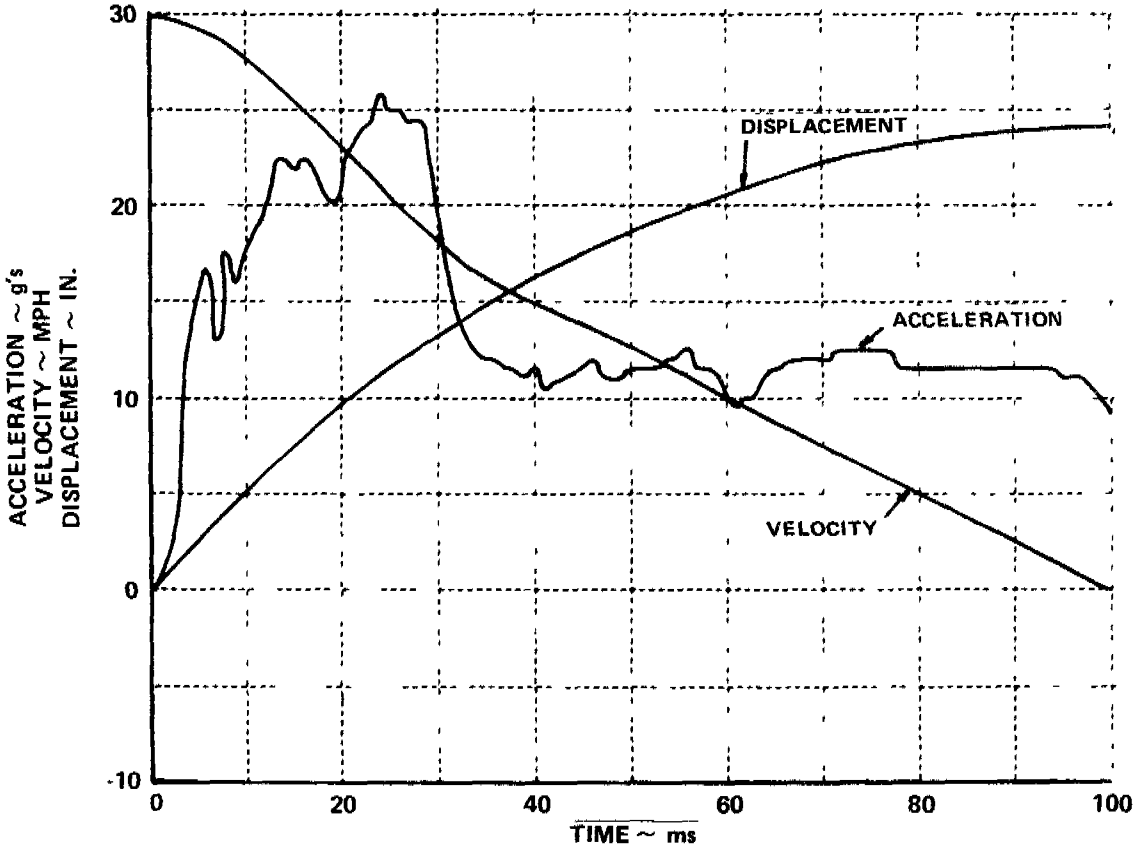


Figure 6-24 PRODUCTION SIMCA REARIMP COMPUTER SIMULATION RESULTS FOR A 30 MPH REAR IMPACT INTO A FIXED BARRIER

6.3 Preliminary RSV Design

In addition to the advantages listed previously related to manufacturing feasibility analyses, use of a base vehicle in the development of the RSV allows the research and developmental effort to be concentrated in certain critical areas. Subsystems which have received particular attention in the Phase I program include the following:

- basic design and styling
- occupant/cargo packaging
- running gear
- bumpers
- crashworthiness structure
- interior components and restraints

In each instance the particular C-6 system has been reviewed in relation to the specifications recommended for the RSV. In instances where improvements in performance over that of the C-6 appeared to be required, alternative designs were investigated. In the following, we present our current preliminary concepts for each of these subsystems and show how these could be combined into a unified vehicle system.

At this point we again re-emphasize our often stated position that although the RSV curb weight will be similar to that of current American subcompact cars, the RSV is not intended to serve a similar mission. That is, the RSV is expected to be a family car which would serve the basic functions of present compact to intermediate size American cars. Therefore, occupant space (4-5 seating positions) and cargo capacity (approximately 15 ft.^{3}) are believed to be essential elements of the vehicle.

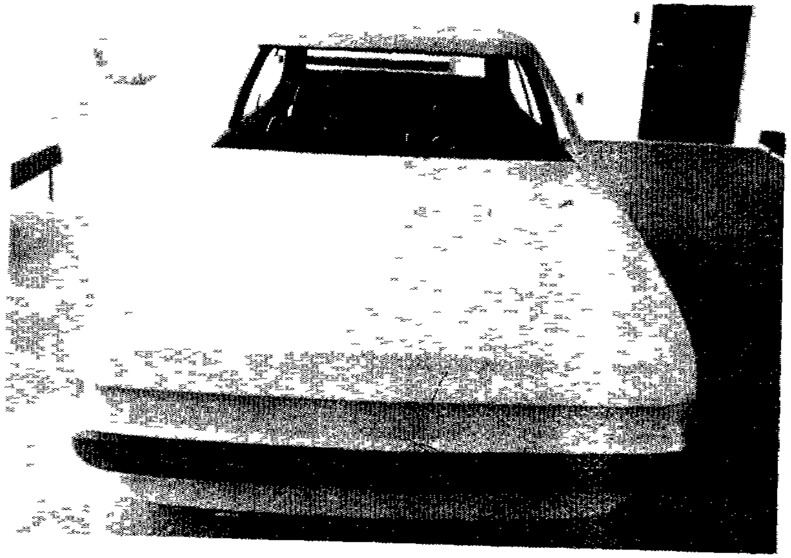
6.3.1 Basic Design and Styling

In this initial phase of the RSV program, a preliminary concept of the RSV has been developed using the Chrysler C-6 as the base vehicle. A mock-up which reflects many of the current ideas pertaining to the exterior and interior of the RSV has been constructed by Chrysler Corporation stylists and modelers. Although many configurations of the RSV are possible such as station wagons, hatchbacks, etc., a basic four-door sedan with a conventional trunk segregated from the occupant compartment was chosen for this initial mock-up effort because the delivered RSV is expected to have this configuration.

The exterior of the RSV mock-up is presented in the series of photographs comprising Figure 6-25. This mock-up reflects dimensionally a three-inch wheelbase increase, which has been added between the firewall and the front wheels, and an increased front overhang resulting from the addition of a soft face for pedestrian impact protection. Other dimensional changes, such as increased width, height, and occupant compartment length, discussed as possible and desirable modifications to the base vehicle to achieve RSV objectives, are not reflected in the mock-up shown in Figure 6-25. The additional cost of including these other dimensional changes in the mock-up was not felt to be justified, considering the very tentative nature of these alternatives at this time.

Included on the mock-up is a front end spoiler underneath to improve under car air flow and hopefully reduce air drag. It is anticipated that the engine cooling air flow will be taken from underneath the face of the vehicle directly in front of the spoiler. This flow area could be cast as an integral part of the soft plastic face bumper system of the vehicle as discussed in Section 6.3.4.

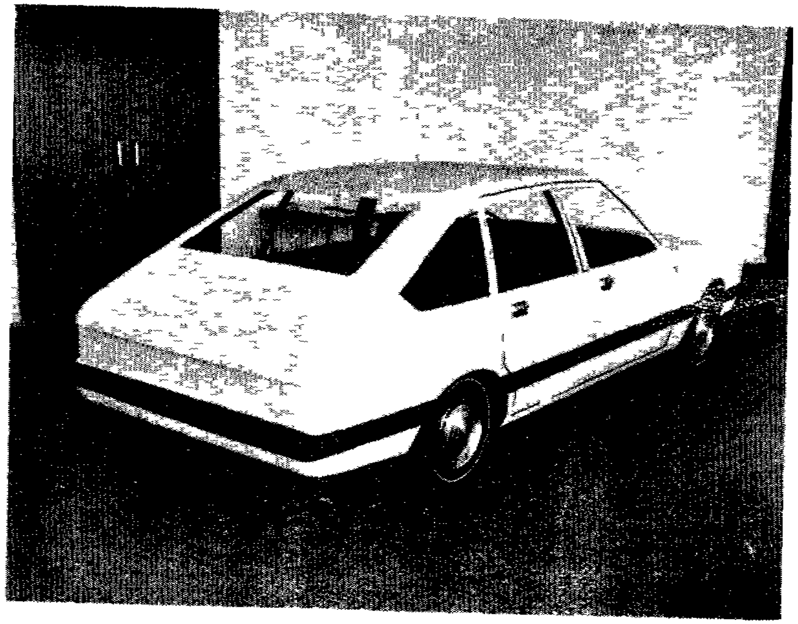
Rectangular headlights, which will conform to the recessed rectangular region shown on the front of the mock-up, will enhance the appearance of the vehicle by presenting a pleasing well integrated image.



a. FRONT VIEW

b. RIGHT FRONT QUARTER

c. RIGHT SIDE



d. RIGHT REAR QUARTER

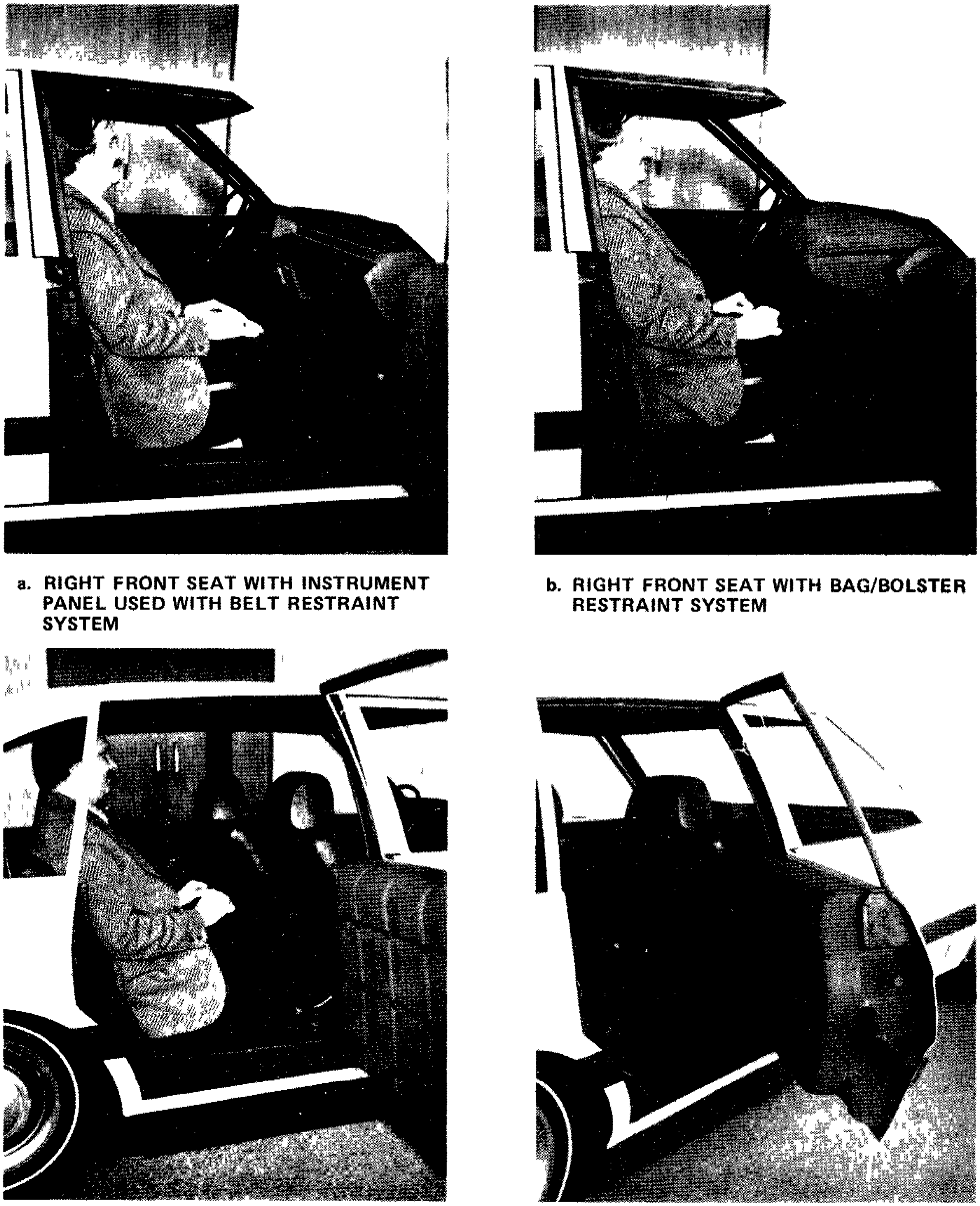
Figure 6-25 RSV MOCKUP EXTERIOR VIEWS

These lights either will be recessed to prevent damage to them during minor impacts which deflect the soft plastic nose or the lights will be mounted in such a manner that they will move aft during minor impacts. The first alternative will, of course, present possible weather associated problems (snow clogging) which may require a second lens covering contoured to the outer surface. This outer lens covering may possibly conflict with some current motor vehicle laws, a problem which will be addressed if this alternative is chosen.

Surrounding the entire vehicle is a rub strip, highlighted with a dark contrasting color in Figure 6-25, which is intended to prevent or minimize minor vehicle damage of the type normally associated with the parking lot environment. This rub strip consists of a raised region of rubber or plastic, protruding beyond the normal surface contour of the vehicle, to ward off shopping cart or other vehicle door impacts. Although the rub strip was purposely colored to contrast on the mock-up with the basic vehicle coloring, the rub strip on the final vehicle could be colored to match the rest of the vehicle and blend with it.

The mock-up color is grey and it is likely that the RSV will be of a light coloring to enhance visibility. The surface finish of the mock-up is quite rough, as can be seen in Figure 6-25, but it was not felt that expending the considerable effort required to improve the surface finish of this very preliminary mock-up represented a prudent use of program resources. The mock-up in its present state of development serves very well to display the basic geometry of the RSV both with regards to exterior and interior.

Interior photographs of the mock-up are shown in Figure 6-26. Figures 6-26a and 6-26b indicate the instrument panel differences in front of the right front passenger depending upon the choice of restraint system used. Figure 6-26a shows essentially the standard C-6 base vehicle panel



a. RIGHT FRONT SEAT WITH INSTRUMENT PANEL USED WITH BELT RESTRAINT SYSTEM

b. RIGHT FRONT SEAT WITH BAG/BOLSTER RESTRAINT SYSTEM

c. REAR RIGHT SEAT

d. DOOR PADDING

Figure 6-26 RSV MOCKUP INTERIOR VIEWS

while Figure 6-26b indicates the modified instrument panel containing a bag/bolster restraint system. The view of the right rear seat, Figure 6-26c is intended to indicate the rear seat roominess of the existing base vehicle. The figure shows the front seat in its most rearward position indicating satisfactory leg room for the rear occupant. One of the explanations for the apparent roominess of the C-6 base vehicle compared to comparable domestic vehicles is that the C-6 seat backs are not as thick as their domestic counterparts.

The remaining interior feature displayed in Figure 6-26 is the door padding shown in Figure 6-26d. This mock-up has been configured internally to indicate both the door padding effects and the interior roominess resulting from the widening modification discussed as a possible alternative in this RSV effort. The left hand side of the mock-up interior indicates only the trim panel texture and not the padding thickness, thereby presenting the true spatial environment of a base vehicle widened to compensate for padding additions. The right hand side reflects the actual padding thickness, on the order of 4 inches, and therefore presents a narrow interior spacing not representative of a widened base vehicle.

The artist's rendering of the vehicle, shown in Figure 6-27 is intended to indicate the more attractive appearance expected from the finished product as opposed to the preliminary mock-up. It should be noted in regards to appearance that a comparison of these mock-up photographs and sketches with Figure 6-1, which shows the unmodified C-6 base vehicle, clearly indicates that the basic C-6 body lines will be retained in the RSV. Furthermore, the lengthening of the base vehicle for the RSV configuration does not detract from the base C-6 appearance but in fact enhances it.

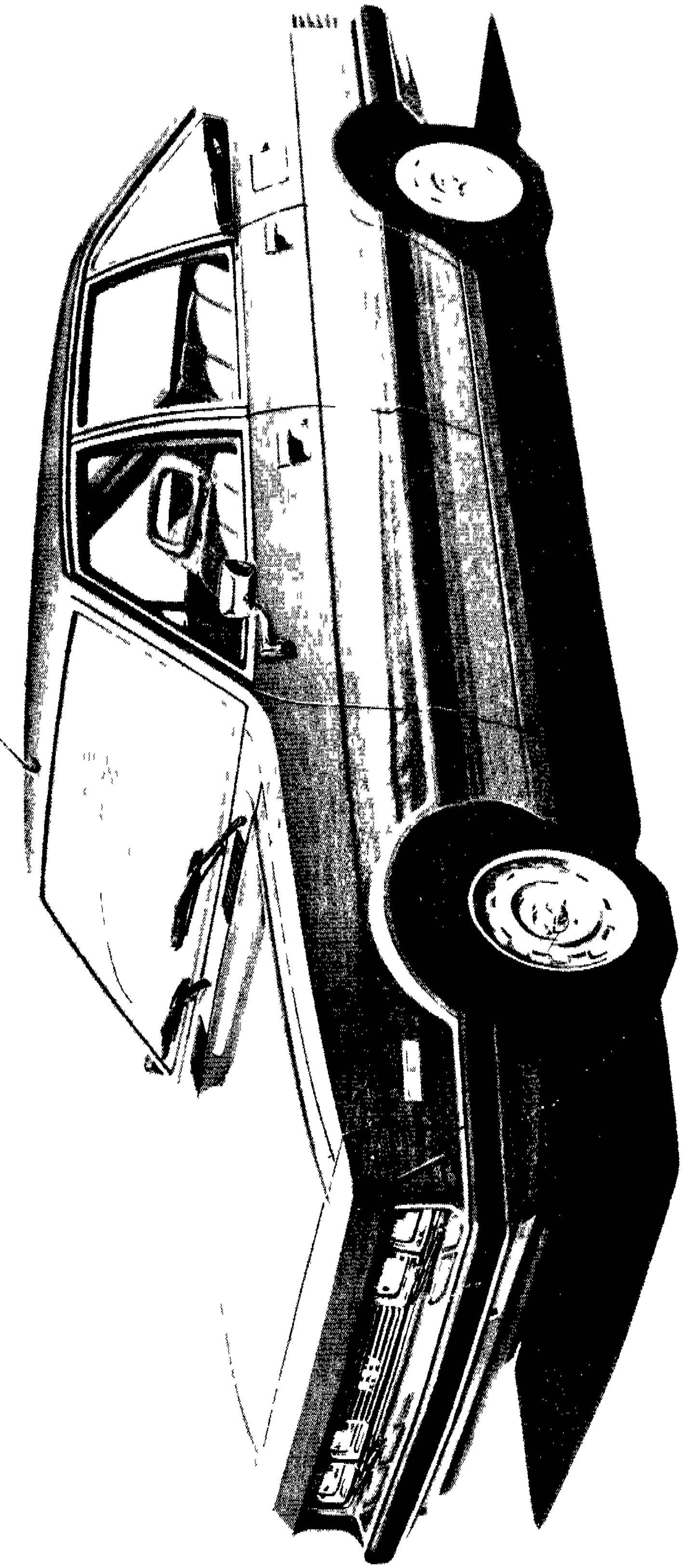


Figure 6-27 ARTIST'S CONCEPT OF RSV

6.3.2 Occupant/Cargo Packaging

Although recommended ranges for both exterior and interior dimensions were developed for the RSV, in reality only the interior dimensions are deemed to be critically important. This is because the interior dimensions essentially define the occupant/cargo space capability for the vehicle. The recommended exterior dimensions were derived from our estimates of what would be required to provide the interior space and related performance for the vehicle. Indeed, if exterior dimensions could be reduced from those given in the recommendations, the result would be an even more attractive vehicle. Consequently, from this point forward, our discussion will center around possible changes to the base vehicle and then potential impact on the interior space configuration.

In Table 6-5, interior dimensions of the C-6 are contrasted with the ranges recommended for the RSV. It is noted that generally the C-6 interior dimensions are acceptable, but only marginally in certain instances. Therefore, we feel that the interior dimensions of the base vehicle should not be reduced while deriving the RSV.

As discussed previously, various vehicle dimensional changes were investigated. Generally, the purposes of these changes would be to at least preserve (or enhance) interior space while developing a suitable crashworthiness structure into the RSV. All of the changes are technically feasible, but may not necessarily be consistent with prudent use of program resources. It should be understood that reconfiguration of the basic length, width and height dimensions of the C-6 constitutes a major design effort. As such, further investigation of the desirability of making such changes in a one-of-a-kind, engineering prototype vehicle must be determined in Phase II. In the following, we discuss our tentative, preliminary thinking concerning possible C-6 dimensional changes.

Table 6-5

INTERIOR DIMENSIONAL COMPARISONS

	C-6	RSV RANGE
FRONT COMPARTMENT		
HEAD ROOM	37.2"	37" - 39"
LEG ROOM	41.1"	40" - 42"
SHOULDER ROOM	54.7"	54" - 60"
REAR COMPARTMENT		
HEAD ROOM	36.4"	37" - 39"
LEG ROOM	36.1"	35" - 38"
SHOULDER ROOM	53.5"	54" - 60"
H-PT. COUPLE	31.2"	–
LUGGAGE COMPARTMENT		
CAPACITY	11.6 ft^3	14 - 19 ft^3

Length

Two different length changes were investigated, (1) increasing the length between the leading edge of the car and the instrument panel, and (2) stretching the passenger compartment at the center pillar.

It is necessary to add about 6" to the front of the C-6 to provide for the pedestrian/low speed vehicle damage bumper recommended for the RSV. As discussed in subsequent sections on bumpers and crashworthiness (Sections 6.3.4 and 6.3.5), the present initial collapse properties of the C-6 appear to be nearly suitable for the second collapse zone. Consequently, the most reasonable way to develop the pedestrian bumper is to add a bumper device to the existing structure. In addition to the bumper, about 3" would be added to the C-6 just ahead of the cowl/dash structure. Addition of structure in this region is most efficient, because as discussed in Section 6.3.5, the greatest energy dissipation per unit of crush occurs when this part of the structure collapses. Accordingly, these changes although not directly related to occupant packaging should be incorporated into the RSV.

As discussed in the crashworthiness section, the center pillars are a key element for improving both longitudinal and lateral impact performance. Furthermore, it would be desirable to have the H-point couple distance increased by about 2" from 31.2" to 33.5". This change would bring the vehicle in line with most current intermediate size American cars with respect to H-point couple. It therefore appeared reasonable to explore stretching the car at the B-pillar location in conjunction with the center pillar modification. Review of alternate center pillar designs indicates that the desired modification can be achieved with modest structural alterations. Additionally, as noted in the discussion on the RSV mock-up, the basic C-6 has a high degree of rear seat passenger room. Because the seat back in this car is not as thick as those in American compact/intermediate cars, strict comparison of H-point couple distances may not be the most effective measure of rear seat room. Thus, the added cost for stretching the car would have to be justified solely on the basis of a need to increase the H-point couple distance. For these reasons we do not feel that this change is warranted during the development of a one-of-a-kind experimental automobile.

Height

It is noted that the C-6 being 54" high tends to be higher than most American cars; contrast this with 50" for Vega and 50.5" for Pinto. Indeed, this increased height tends to permit a more erect seating posture, thereby increasing head and leg room dimensions in relationship to longitudinal length. Increasing the height could allow even higher seats and correspondingly minor increases in respective head and leg room dimensions.

It is noted that the present C-6 has a relatively flat roof. Thus, the roof panel could be replaced with a panel having a greater crown without adversely affecting overall design. This change, which would increase vehicle height by about 1" to 2" would permit some flexibility in seating arrangement. It is, therefore, felt that further consideration should be given to this possible design change in Phase II of the program.

Width

The C-6 interior space is most marginal with regard to width (see shoulder room dimensions in Table 6-5). Because of the recommended side impact crashworthiness requirements, the width of the side walls of the car must be increased from their present width dimensions. The alternatives are then either to reduce compartment interior space, already at minimum levels, or to widen the base car.

There is a natural reluctance to widen the car because so many components are involved. Also, this effort would result in an important impact on program resources. Therefore, we do not feel that it would be appropriate to definitely indicate at this time that the car would be widened. Note that the mock-up structure was not widened. Instead, thicker side walls (doors) were placed on the passenger side while narrow ones were placed on the driver side. The mock-up structure then simulates both conventional and widened vehicle interior characteristics. We feel that the ramifications of this change should be more fully explored in Phase II of the program. Below, a procedure which was briefly investigated in Phase I is outlined.

Any technique used to widen the C-6 must serve two main objectives, (1) maintain present interior configurations, particularly the driver seat to control relationship, and (2) provide for minimum changes on the remaining vehicle components. The scheme which appears to satisfy this objective is shown in Figure 6-28. Note that the breaklines shown in Figure 6-28 are intended to conceptually illustrate the technique, actual breaklines would follow specific vehicle part and contour lines. To preserve present suspension characteristics, the vehicle would be cut near the centerline in the fore and aft sections. On the other hand, the passenger compartment breaklines would be outbound at the interior seams of the sidewalls. The modified vehicle can be conceptually understood by visualizing a splice at each of the breaklines However, in the actual vehicle, many of the structural components would, indeed, be replaced and in these instances no physical splice would be installed.

It is also noted in Figure 6-28 that the breakline at the cowl/dash area extends to the sides of the car. It is at this location that 3" of structure would be added to provide greater crush during frontal collisions (see previous discussion on length changes).

Finally, we again note that from an occupant space viewpoint, it is critically important that the RSV exhibit 4-5 place seating capability. Otherwise, the final RSV would not be consistent with the basic objectives developed for this vehicle development program. Quite likely, not all of the above changes would be incorporated into the final vehicle; but, in any event, the delivered RSV must represent an automobile having family mission capability.

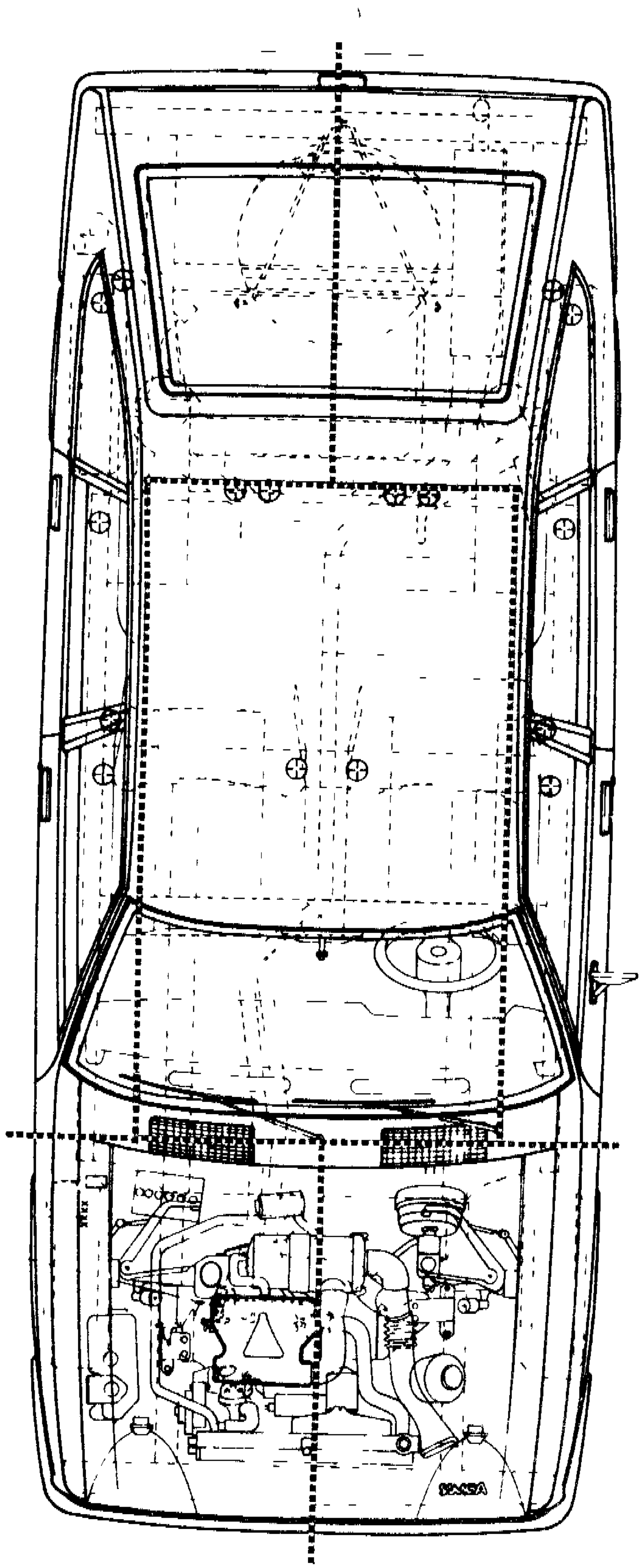


Figure 6-28 ILLUSTRATION OF BREAKLINES FOR WIDENING AND LENGTHENING BASE VEHICLE

Luggage Compartment Capacity

Because the RSV is expected to satisfy family transportation needs in the mid-1980's, it is important that this automobile demonstrate adequate luggage capacity. Presently, most standard size cars provide about 20 $ft.^3$ of luggage capacity. We do not believe that volumes of this magnitude are absolutely necessary with a small car; but, volumes near 15 $ft.^3$ appear possible with extremely modest changes to the base vehicle.

It is noted that the RSV is presently configured as a 4-door sedan hatchback, commonly called a 5-door sedan. With the rear seat in the seating position, the vehicle provides 11.6 $ft.^3$ of volume for luggage. We expect the RSV to be configured only as a 4-door sedan; consequently this value is taken as the base condition.

As noted elsewhere, run flat tires are planned for the RSV. Furthermore, the present 15 gallon fuel tank appears to be more than adequate for normal driving requirements. (Note, a 30 mpg, 55 MPH cruising fuel economy results in a range of 450 miles.) Therefore, in the interest of improving luggage capacity, the space now occupied by the spare tire and part of the fuel tank would be converted to useful luggage space. This modification essentially involves a redesign (lowering) of the present trunk floor. In this way, it is felt that useful luggage capacity can be increased to about 16 $ft.^3$.

6.3.3 Running Gear Components

As indicated previously, the C-6 automobile employs a transverse front engine, front wheel drive propulsion system. A 1440 cc displacement engine available in the C-6 is expected to be used in the RSV. But, it is noted that the C-6 will also be available with a 1300 cc displacement engine. In addition, this basic engine/drive system has been developed and marketed in 1100 cc and 1200 cc versions with previous car models. We might, therefore, elect a smaller displacement engine for the RSV if this engine would have an important effect on improving fuel economy.

The data relative to fuel economy and vehicle acceleration performance, presented in Figures 6-2 and 6-3 are based upon the 1440 cc engine. Similar analyses would be performed for each of the candidate smaller engines. At this point we assume that the consideration of all engine options would suggest trade-off possibilities between fuel economy improvement with reduction in vehicle acceleration performance. Additional analyses would be performed during Phase II to define other technical improvements that might be incorporated into a base engine. In any event, we would not anticipate replacing the C-6 engine (except, possibly, with one of the compatible predecessors) with a different power system. Such an undertaking would involve engineering and design effort well beyond the scope and resources of the RSV program.

The basic running gear and drive components for the C-6 are illustrated in Figure 6-29. Important features which are illustrated are the previously mentioned transverse engine, front wheel drive system, torsion bar front suspension, rack and pinion steering, and independent, coil rear suspension. These basic components are expected to remain unchanged in the RSV derivative except as required to make the vehicle wider.

As discussed previously, we feel that it would be highly desirable from an occupant/cargo capacity viewpoint to widen the C-6 when developing the RSV. But, it was also noted that such an undertaking requires substantial engineering and developmental effort. In the event that the vehicle were widened, however, corresponding changes in the running gear elements would also be necessary. These would include lengthening the drive shafts, altering the steering mechanism, and adjustments in the suspensions. (Added weight associated with the RSV will likewise impose some changes on suspension components.) The RSV in the wider configuration would have a correspondingly 4" wider tire track (e.g., front tread width from 55.7" to 59.7"). Incidentally, these changes would probably be generally favorable to overall vehicle handling.

The spare tire will be eliminated in the RSV. We believe that "run flat" tire development is in an advanced stage and such tires will be common on most automobiles before the mid-1980's. Recommendations for this

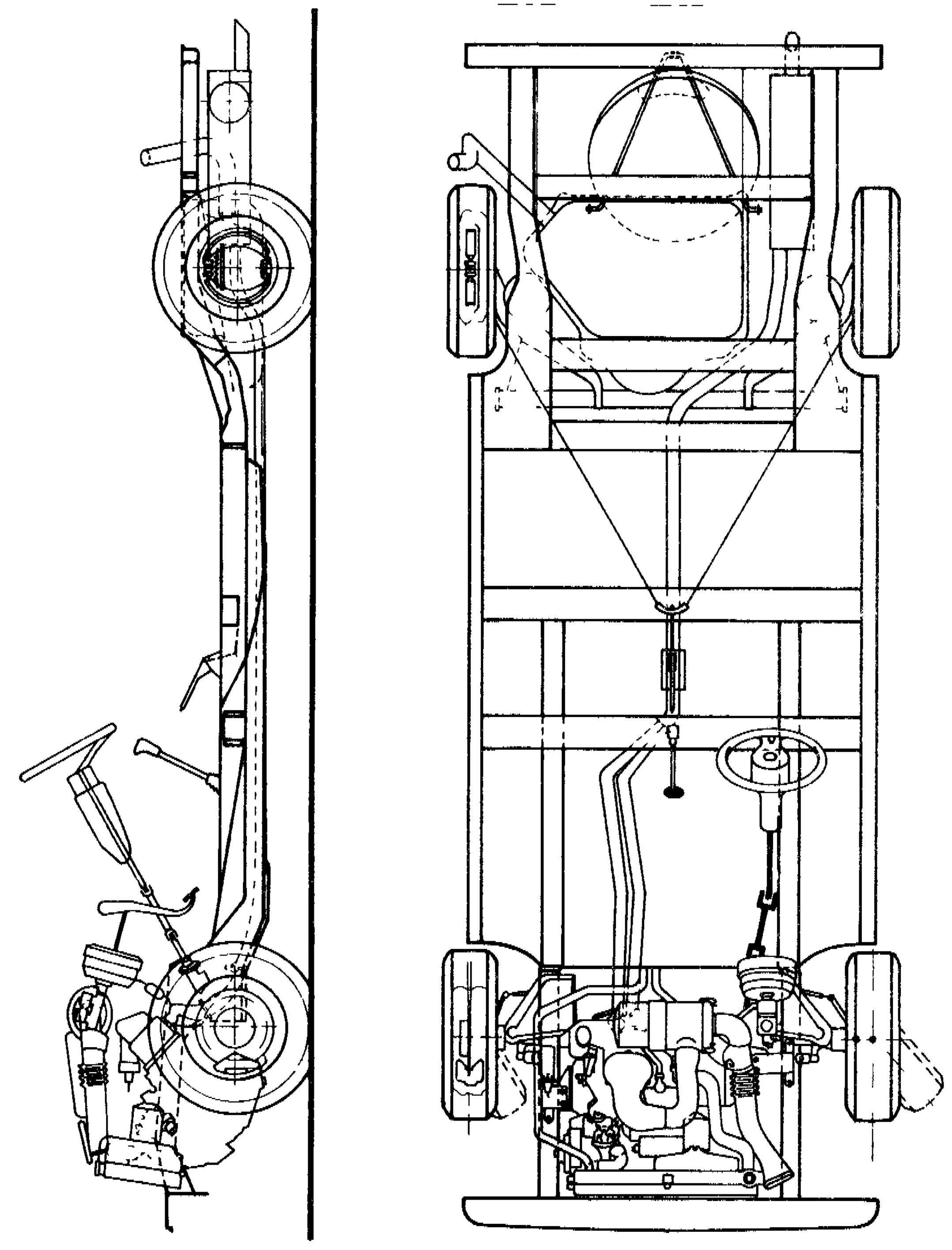


Figure 6-29 SCHEMATIC ILLUSTRATION OF C 6 RUNNING GEAR COMPONENTS

approach relative to the RSV stem from two considerations. First, elimination of the spare tire permits greater cargo capacity within the trunk region. This factor is particularly important in smaller car designs which attempt to optimize space in relation to weight. Second, and most important from a safety standpoint, elimination of the spare tire will reduce potential for loss of control during blowouts and eliminate roadside tire repair. Thus, in this process a particularly hazardous and dangerous activity will be removed from the highway scene.

The run flat tires tentatively planned for the RSV are under development by Goodyear. The objectives of the Goodyear program are:

- If tire failure occurs, car and driver can continue for 50 miles without the necessity of stopping.
- Operation can be at highway speeds up to 50 MPH.
- Blow-out protection also to be provided.
- System to be completely self-initiating.
- Conventional tires and wheels to be part of the system because of good ride as well as repair and replacement availability.
- Elimination of spare tire and wheel.
- After puncture repair, system can be reused.

With conventional tires and wheels established as part of the package, a device was devised that will fit on the rim inside the tire cavity to support the inside of the tire during zero inflation. The device is fully capable of carrying the rated load of the tire, low enough so that road bumps will not allow the inside of the tire to contact the device and yet high enough to support the tire at a diameter that keeps the tire from being destroyed when being "run flat".

The device developed to accomplish these objectives is a two-piece fiberglass reinforced resin part referred to as a stabilizer. The device is shown in the photographs of Figure 6-30 and can be assembled on conventional wheels. Very early in the program, it became apparent that a lubricant was required to reduce the friction between the outside diameter of the stabilizer and the inside surface of the tire. Equally important was the development of a lubricant dispensing means. The picture shows the bulb containers holding the lubricant inside the stabilizer. A rubber nipple projecting through the stabilizer shears off when the tire goes flat, thus dispensing the lubricant. The standard test is 50 miles at 50 miles per hour, no valve stem, and the car loaded to the tire rated load. Goodyear has successfully completed 130 of these runs while varying various parameters, with many parts having been run multiple 50 mile sequences. The majority of the testing has been conducted using an HR78-15 tire size (1510 lb. load). The system is now in service on a commercial test application, private cars and on their own test fleet.

It presently appears that four of these devices could be installed on an automobile for the same cost as providing a spare. Associated with this change would be a component weight savings of about ten percent, or for the RSV about 15 lbs.

We fully appreciate that certain individuals may prefer (and indeed demand) a spare tire. A spare tire could be included as an option in the RSV and appropriate means for tire tie-down in the trunk region provided. In addition, normal jacking points (located in the underbody forward and rear portions of the sills) and present C-6 jack would then be provided.

Figure 6-30 GOODYEAR RUNFLAT TIRE SYSTEM

Because of the added weight envisioned for the RSV, tire size (wheel diameter) will be increased from 13" to 14". This change is necessary to accommodate added load as well as improved brakes necessary for the RSV.

Brakes must be considered an important element in any automobile, especially an RSV. Changing the wheel size (i.e., increasing the wheel diameter) would allow the incorporation of larger diameter brake discs and drums in the C-6 braking system. For this change, it is felt that brake units from Chrysler domestic automobiles (compact class) could be used, if the RSV has 14" diameter wheels. Thus, the RSV, having a lighter weight than domestic compacts, would also exhibit superior braking properties.

We also note that the C-6, as is consistent with European practice, requires more maintenance service of brakes than is the custom with U. S. domestic cars. The C-6 brakes are designed for about 10,000 miles and then replacement of the brake pads are expected as part of normal maintenance. Changing the brake system to U. S. components would bring service requirements more in line with current U. S. practice.

6.3.4 Bumper Systems

A "soft front" design was selected for incorporation in the RSV. Pedestrian/cyclist protection and damage reduction features are concentrated in this area. Justification for this approach was detailed in Volumes II and III; and that justification is abstracted here.

Background

Pedestrian accident analyses show:

- In 76% of contacts the striking vehicle was going straight.

- Almost 80% of impacts were with the front of the car.

- The hood edge, bumper, forward hood and grille are the dominant injury producing vehicle elements.

- Designing the front of the vehicle for pedestrian accidents occurring at speeds up to 20 MPH would influence injury severity in over one-half of all pedestrian accidents.

Estimation of soft face effects on damageability required recognition of the importance of the front structure in vehicle/vehicle impacts and the dominance of vehicle/vehicle collisions in damage accidents. Table 6-6* illustrates that about 90% of damage producing accidents involve vehicle/vehicle collisions--hence, the emphasis on seeking damage reduction in this mode. Table 6-7* summarizes the dominance of front end involvement in these vehicle/vehicle collisions. The two independent sources of information (Tri-Level II accident investigations and National Association of Independent Insurers) are in agreement on accident configurations.

The damage accident modes suggest that associated costs would be concentrated in the vehicle frontal area. This is confirmed in the surveys of insurance and manufacturers repair cost experience shown in Table 6-8.* It is emphasized that the introduction of a soft front impacting sides and rears of other cars distributes the loads and would reduce damage to sides and rears. Table 6-8 again confirms that cost of repairs (from both manufacturer and insurance sources) tends to be concentrated in frontal components.

---

* From Volume II.

Table 6-6

FREQUENCY OF CLAIMS BY ACCIDENT TYPE

ACCIDENT DESCRIPTION	TRI-LEVEL II	NAII
SINGLE VEHICLE	1,605 - 12.0%	983 - 5.2%
VEHICLE - VEHICLE	11,816 - 88.0%	17,788 - 94.8%
TOTAL	13,421	18,771

Table 6-7

CLAIM FREQUENCY FOR VEHICLE-VEHICLE ACCIDENTS

ACCIDENT TYPE	TRI-LEVEL II	NAII
FRONT - FRONT	851 - 8.5%	1,655 - 9.8%
FRONT - REAR	4,412 - 44.1%	7,773 - 46.1%
FRONT - SIDE OR REAR - SIDE	4,736 - 47.4%	7,428 - 44.1%
TOTAL	9,999	16,856

Table 6-8

DISTRIBUTION OF REPAIR COST EXPENDITURES

IMPACT AREA	FOUR COMPANY	STATE FARM	FORD
FRONT	64.0%	40.9%	49.4%
FRONT CORNERS	31.5%	25.9%	23.3%
FRONT CENTER	22.5%	15.0%	26.1%
SIDES	22.5%	30.0%	19.5%
REAR	23.5%	29.0%	30.6%
REAR CORNERS	9.0%	13.7%	15.3%
REAR CENTER	14.5%	15.3%	15.3%
	100.0%	99.9%	99 5%

Because of the high involvement of the front in accidents (in terms of both frequency of occurrence and cost), most of the effort for reducing damage and costs should be concentrated in the front of the vehicle.

If a no damage front end (5-10 MPH) is solely incorporated in the RSV design, most of the damage and costs associated with fenders, front bumper, headlights, grille, hood, and radiator, etc., would be eliminated. This would constitute between 40-60% of all damage costs (see Table 6-9). Just by modifying the front, substantial savings could be made.

There is very little one can do to the side structure beyond using a rub strip, because it is basically a sheet metal structure. However, if a soft nose front were used on the RSV, not only would front damage be lessened, but also the side structure components (doors, quarter panels, and fenders) would experience reduced damage in a front to side collision. Of course, this argument can also be extended to the rear. Only a conventional rear bumper system would be needed since, in front to rear collisions, the soft front would "protect" the rear components (bumper, trunk, quarter panel, tail lights, etc.) from damage.

Table 6-6 indicates that very few vehicles are involved in single vehicle accidents (less than 10%) and that the front of one vehicle is involved in almost all multi-vehicle accidents. Thus, a soft front nose concept, employing a recoverable plastic skin, could potentially affect 80-90% of all low speed damage costs. At this point, it is premature to estimate the precise potential because the concept must first be tested under various car-to-car impact conditions. Once such test data are available, it would be possible to provide a more exact estimate. Nevertheless, it is clear that such front structure redesign has considerable potential as a damage reduction countermeasure for most types of vehicle damage accidents.

Modification of the front bumper area to reduce pedestrian fatalities implies low <u>local</u> collapse pressures and reasonable stroke (4" - 6"). Such a "bumper" would not pass the pendulum tests of FMVSS 215 because the pendulum

Table 6-9

AVERAGE COST OF REPAIR BY COMPONENT PER INCIDENT

COMPONENT	AVERAGE COST		% OF TOTAL	
	FORD	STATE FARM	FORD	STATE FARM
QUARTER PANEL	$73.56	$53 43	24.8	16 5
PAINT	N.C.	50.43	–	15.5
FENDER	47.40	41.70	15.9	12 8
FRONT BUMPER	21.58	32.32	7.3	10.0
HOOD	20.00	12.72	6.7	3.9
FRONT DOOR	19.02	20.60	6 4	6.3
DECK LID	14.79	7.16	5.0	2 2
REAR BUMPER	13.50	26.78	4.5	8.2
GRILLE	13.12	13.59	4.4	4.2
HEADLIGHTS	10.50	7.14	3.5	2.2
LOWER BACK PANEL	8.20	N.C.*	2.8	–
FRAME	7 83	20.69	2.6	6 4
RADIATOR	7 38	9.42	2.5	2 9
TAIL LIGHTS	6.78	2.50	2.3	.8
REAR DOOR	5.00	5.85	1.7	1 8
WINDSHIELD	3.85	5 03	1.3	1 5
OTHER	23.67	15.33	8 0	4 7
TOTAL	297.00	324.69	100.0	100 0

N.C NOT CONSIDERED AS SEPARATE ENTITY

FORD DATA IS DEALER REPAIRS

face would necessarily contact the grille/fender area. Detailed arguments for abandoning the current form of FMVSS 215 were presented in Volume III. It was shown there that the equation governing exhaustion of front-to-rear energy management capabilities* is

$$V_f^2 + V_r^2 = k^2$$

where V_f and V_r are the barrier impact speeds at which the front and rear bumper energy absorption are saturated. System performance (allowable closing speed) is $V_o = \sqrt{2}\,k$. The pictorial representation is repeated here as Figure 6-31; Point "A" on Figure 6-31 corresponds to 1973 bumpers (5 MPH front, 2-1/2 MPH rear) and represents a 7.9 MPH system; Point "B" corresponds to 1974 bumpers (5 MPH front, 5 MPH rear) and represents a 10 MPH system; points along the arc from the ordinate to Point "D" represent the range in which the RSV system would fall and all correspond to a 13 MPH system. Hence, the RSV performance specification is a substantial increment over present systems--and at a weight savings if the C-6 rear bumper system remains substantially unchanged (Point "E"). In its functional roles, then, the RSV soft front would play a part in:

- pedestrian/cyclist impacts
- multi-vehicle accidents

  front/side
  front/rear
  front/front

- single vehicle frontal collisions

---

* Equal weight cars.

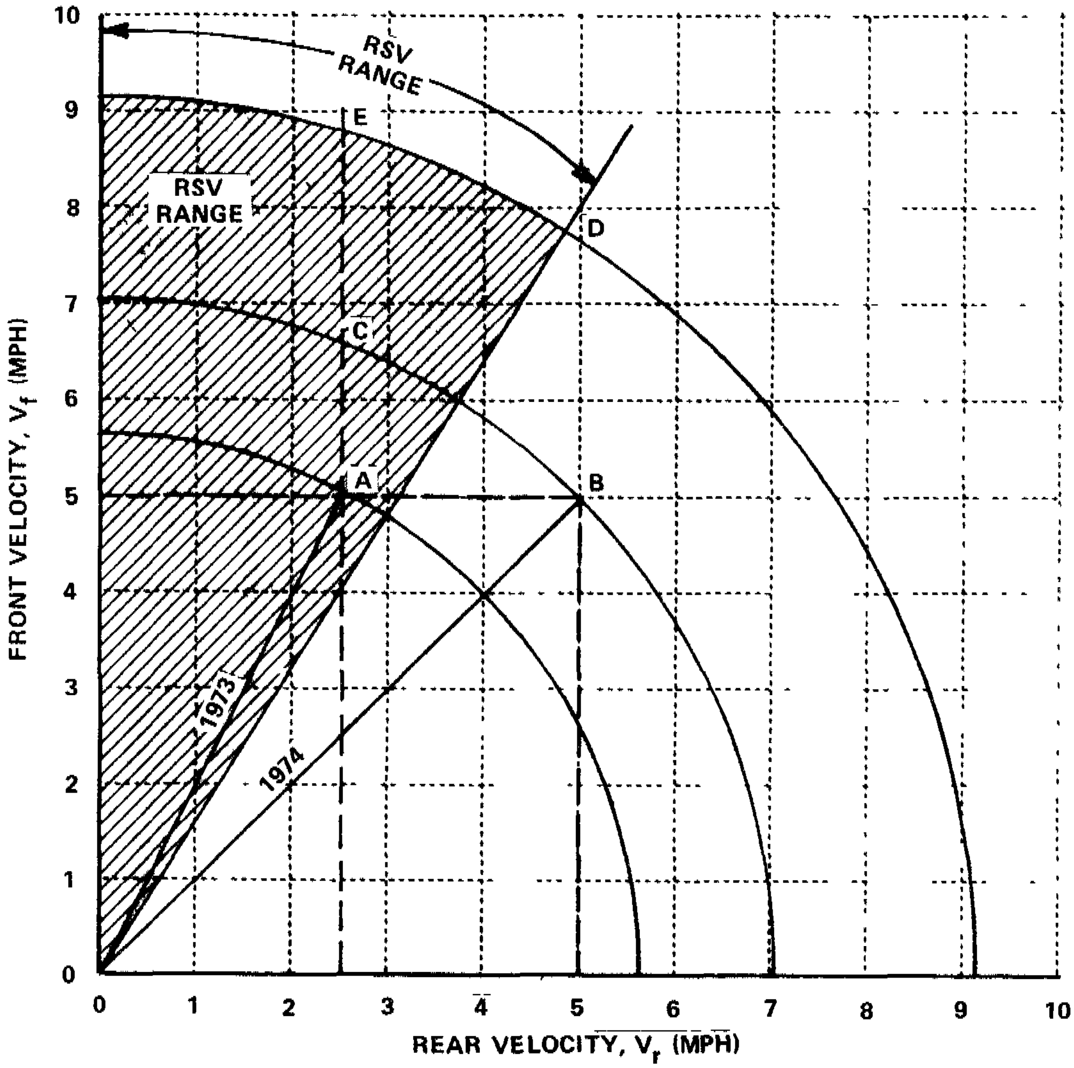


Figure 6-31 RELATIONSHIP BETWEEN FRONT AND REAR BUMPER PERFORMANCE

The "bumper" is a major factor in low energy incidents and must be relatively soft; but in high speed impacts a soft bumper would correspond to a loss of available crush. Resolution of this apparent conflict is sought in the following manner:

1. Adopt a design that is locally soft for pedestrian/cyclist impact.

2. Adopt a design that deforms to provide a large area of contact with other vehicles.

3. Keep the weight of the soft element very low and "add" it to the vehicle front--that is, increase the front overhang without compromising suspension loads.

At this point it is necessary to define "soft" in terms of pedestrian impacts. Our review of tibia and lateral chest tolerances leads us to a tentative specification that local crushing pressures on the soft face should be in the range 15-25 psi. We find no current vehicle designs that approach this range and, hence, conclude that concepts must be advanced and tested in Phase II. Two preliminary candidate designs are advanced. First, however, compatibility of these low collapse pressures with damage reduction is explored briefly.

Corner hits (say, 45° into another RSV) would develop an increasing area of contact (with penetration depth) having a characteristic height of about 2 feet. At a constant pressure of about 25 psi and a stroke of 6", the two vehicles could collide at a closing speed of over 8 MPH without damage. A flat frontal barrier impact at an average pressure of 15 psi, and an average height of about 12" would produce deceleration forces approaching the allowable front structural loads in zone II_f -- a no damage impact speed in excess of 10 MPH could be obtained.* It is concluded that there need not be an incompatibility between pedestrian protection and damageability in frontal impacts.

* Limited by the ability to transfer the loads efficiently and without damage into the back-up structure.

Soft Front Concepts

Soft front concepts should satisfy the following performance criteria:

- collapse pressures in the range 15-25 psi
- stroke 4-6"
- shape recovery

Recoverability dictates a plastic material such as polyurethane, neoprene, or polyvinyl buterate. Low collapse pressure requires a thin shell or a honeycomb with large cell size. Both are recommended for study in Phase II.

Figure 6-32 shows a schematic of a possible soft face. A thin skin would cover the entire front end. Stabilizer ribs (plastic) support the skin and carry low level loads into the upper cross member and into the structural part of the drag dam. In this arrangement the drag dam also acts as a scoop to direct air through lightening holes in the lower skin face to the radiator.

Design parameters are (1) the choice of material, (2) the thickness of the skin, (3) the contour of the facing, (4) the thickness of the ribs and (5) the spacing of the ribs. Some degree of variability will be experienced across the width because the collapse loads will be higher at the rib locations (the ribs must deform under low loads to avoid defeating the pressure criterion, and there are advantages to choosing the same plastic for the ribs as for the skin). Non-uniform rib spacing offers some control over the force "profile" of the front -- higher collapse pressures probably being desirable at the corners.

No known data exist on such designs. The unpressurized bumper being developed by USM Corporation and the pressurized air bumper (Ref. 6-18) advocated by the firm, Safety Consultants, Inc., have collapse pressures that are too high ($>$ 60 psi) for pedestrian protection. Candidate materials are reviewed in a later section.

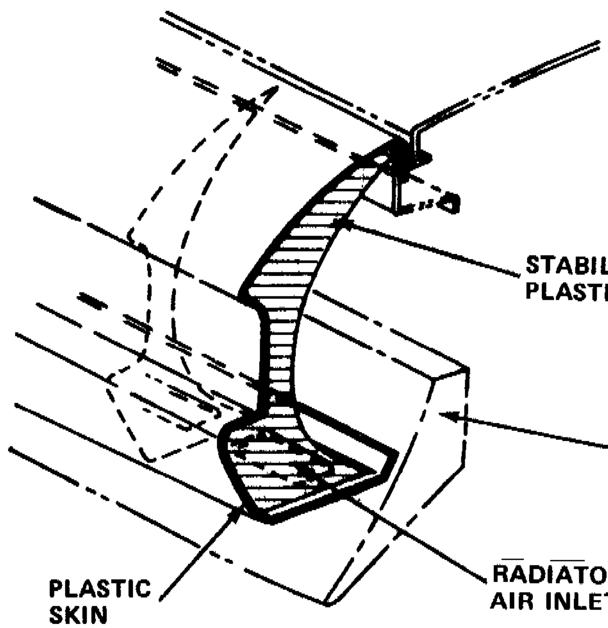


Figure 6-32 RIB-STABILIZED SOFT FRONT

Figure 6-32 shows a second soft front scheme. Open honeycomb cells in the center permit air passage to the radiator. In the other areas, the honeycomb stabilizes the face skin. Use of a backing skin permits load transfer to upper structure and to the structural portion of the drag dam. Venting of the back skin protects against moisture collection and the size of the vent determines the extent to which air compression participates in the energy absorption.

Design parameters are (1) the choice of material, (2) the thickness of the skin, (3) the contour of the facing, (4) the thinkness of the honeycomb walls, (5) the cell size of the honeycomb, and (6) the venting of the nominally closed cells. Cell venting provides some control over local collapse loads--again, some stiffening at the corner positions is probably desirable with respect to damageability.

All the previous discussions have emphasized the necessity of obtaining a front structure that would protect the pedestrian and be compatible with damage reduction. Of major concern are the selections of materials and designs that are consistent with these aims and the test methodology that will confirm the selections. These items are discussed next and are followed by a description of some preliminary test results.

<u>Materials/Processes</u>

Material selection is involved primarily with the achievement of low collapse pressures for pedestrians.* There are, however, the practical considerations of --

- temperature effects
- dimensional stability
- producibility, availability
- finish
- cost
- reclamation (recycling)

*It is, of course, understood that the geometric design interacts strongly with the material properties in fixing the collapse loads.

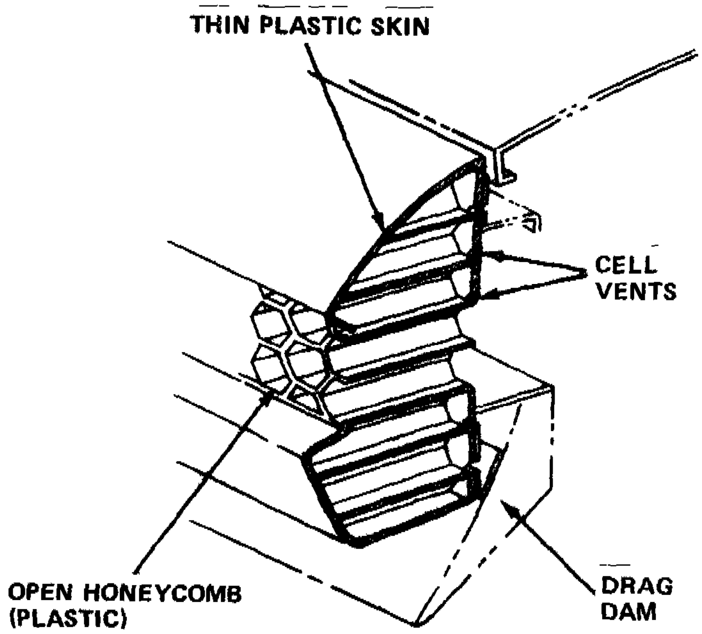


Figure 6-33 SOFT FACE PLASTIC HONEYCOMB CONCEPT

Review of plastics currently in use or development by the automotive industry is in order because most of the items in the above list have been addressed in applications. Three polymeric types have been used or proposed for flexible parts on the front of a vehicle. Significant material characteristics of each type are listed in Table 6-10. Of the three materials, the thermosetting urethane foam material, process and application technology is at a more advanced stage of development, as regards flexible fascia for automotive front ends. Using reaction injection molding, production parts are feasible and practical for flexible front ends. Finish matching and color matching with adjacent metal parts are feasible.

Processing and producibility characteristics associated with the above plastics are summarized in Table 6-11. The three are competitive with respect to automotive processing, cycle time, producibility and minimum gauge. Thermoplastic urethane has a distinct advantage, at this time, over the EPDM elastomer from the standpoint of reclamation. Recycling possibilities for thermosetting urethane foam are not yet evaluated.*

Auxiliary Considerations

Headlight details deserve attention because they represent a potential hazard to pedestrians/cyclists and, at the same time, are related to causal factors through aiming (visibility for the driver and glare source for on-coming vehicles). Headlamps cause a discontinuity in the soft front. Recessing the lights 6 inches at least would remove the glass and fixtures as injury

*It is probable that thermosetting urethane foam would be chosen for the initial subsystem development for the RSV. Thermosetting urethane foam, using an inexpensive cost epoxy tool can be utilized to obtain "first" parts that will approximate the production version using liquid (reaction) injection molding technology. These first parts can be "hand built," behind the skin surface, to increase or decrease deflection characteristics of the fascia.

Table 6-10

PROPERTIES OF CANDIDATE MATERIALS FOR SOFT FRONT FACE APPLICATION

	THERMOSETTING URETHANE FOAM	EPDM ELASTOMER	THERMOPLASTIC URETHANE
SPECIFIC GRAVITY	1.0	1.25	1.18
TENSILE STRENGTH (psi)	2,400	1,800	3,200
UNSUPPORTED SAG (HEAT EFFECT)	GOOD	GOOD	FAIR
FORMULA FLEXIBILITY	YES (RIGID CRUSHABLE) (SEMI-RIGID) (FLEXIBLE)	NO (GLASS FILLER ADDITIONS)	SOMEWHAT
RELATIVE RAW MATERIAL COST ($/LB)	1.25	1.0	2.0

Table 6-11

PROCESSING AND RECYCLING CHARACTERISTICS OF CANDIDATE SOFT FACE MATERIALS

	THERMOSETTING URETHANE FOAM	EPDM ELASTOMER	THERMOPLASTIC URETHANE
PROCESS EMPLOYED	CASTING, LOW PRESSURE INJECTION	HI-PRESSURE INJECTION	HI-PRESSURE INJECTION
TOOLING EMPLOYED	EPOXY, ALUMINUM, ELECTROFORMED MOLDS	MACHINED STEEL	MACHINED STEEL
EQUIPMENT NEEDED	HI-PRESSURE IMPINGEMENT MIXER, LOW PRESSURE FILL 100 psi	HI-PRESSURE INJECTION FILL 4,000 psi	HI-PRESSURE INJECTION FILL 4,000 psi
CYCLE TIME (MIN.)	4 (NOW) 2.5 (NEAR FUTURE)	3	1.2 - 1.5
THICKNESS LIMITATION (IN.)	0.120 MIN.	0.150 MIN.	0.120 MIN.
RECYCLEABLE	?	NO	YES

producing items. This may not be practical from the standpoint of ice and snow removal; possible alternatives are sought. In particular, axial motion freedom under loadings of the order of 20 psi would reduce the injury potential of the lighting unit. Conceptual designs that could provide axial freedom are shown in Figure 6-34.

Return of the headlight fixtures to their proper positions after low speed impact is one of the functions of the guide/spring arrangements. This is, however, a secondary requirement compared to removal of the pedestrian/cyclist threat. Furthermore, the mechanical aiming adjustment on the C-6 would be retained so that slight misalignments (and adjustment for load distribution) could be corrected. This mechanism is a simple cam and detent that is convenient to operate.

An attractive alternative may be the placement of scratch resistant plastic covers over recessed headlights. We recognize that such a solution may be in conflict with some current regulations (both state and federal). Nevertheless, if future study indicates that such an approach does not degrade lighting and indeed improves pedestrian protection, we would then certainly recommend this design for the RSV.

Headlamp washers and wipers already available (as options) on the C-6 would be retained.

Developmental Test Methods

It was pointed out in Volume III that very little is known about effective pedestrian/cyclist hazard reduction. The final arbiter -- significant real world accident statistics supported by controlled laboratory measurements -- supports only the position that current protection systems are grossly inadequate. There are no data on soft front vehicles.

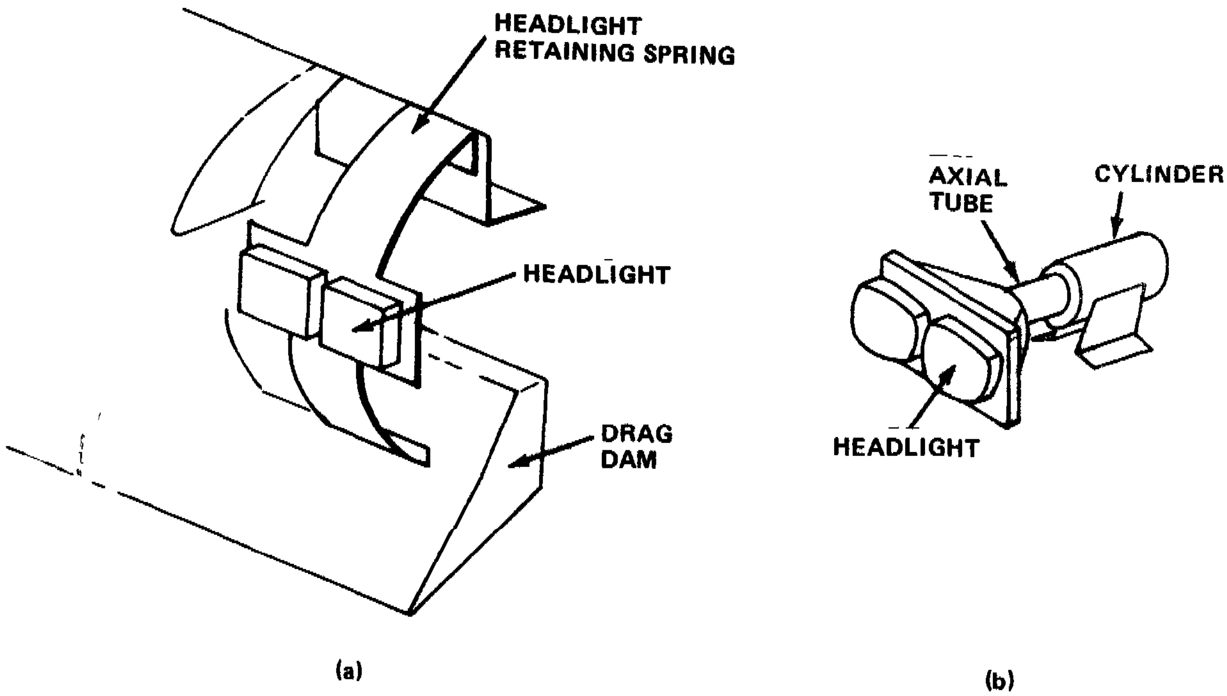


Figure 6-34 HEADLAMP RETENTIONS

Laboratory investigations have raised as many questions as they have answered. Current studies* that include measurements on human surrogates indicate, for example, that sizable axial forces are introduced in the legs of pedestrian human surrogates when they are struck by braking vehicles.

We raise the above points in order to emphasize that there is no hard experience that defines a correct test procedure. A beginning must be made; and we opt for a simple test mode used previously at Calspan to provide engineering data on interior padding design (Ref. 6-19 and Volume III of this series).

Soft front candidate sections should be fabricated and tested. The initial aim would be demonstration of performance specified in Volume III:

> When impacted at speeds up to 22 MPH by a vertically oriented body block, front face energy absorption should be provided so that decelerations on the body block do not exceed 60 g's for time intervals of more than 3 milliseconds. All impacts should be in a direction parallel to the longitudinal axis of the vehicle. The body block should have the following characteristics:
>
> - hardwood form
> - one-half inch impact surface covering of ensolite or equivalent material
> - weight of 100 lbs.

*Personal communication with Mr. Howard Pritz (Battelle Columbus Laboratories, DOT Contract No. DOT-HS-361-3-745).

Accelerations should be measured at the center of gravity of the body block and processed with an SAE class 180 filter. The vertical length of the body block should be sufficient to span the vertical surface dimension of the front of the RSV.

Figure 6-35 shows the Calspan Linear Accelerator used to conduct such tests (Ref. 6-19). A brief discussion of some preliminary soft bumper tests (conducted with this test rig) is presented next.

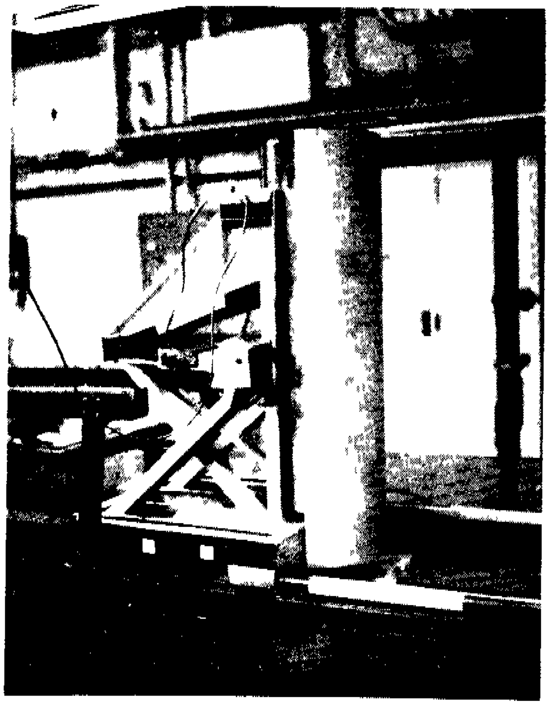
Preliminary Bumper Test Results

Tests were conducted with a simple soft bumper impacted by the test device described in the previous section. The main purpose of the runs was to establish the feasibility of obtaining very low local collapse pressures. Attention was focused on the skin since this represents the irreducible minimum loads -- any subsequent stabilization to maintain contour (appearance) would necessarily increase the local pressures.

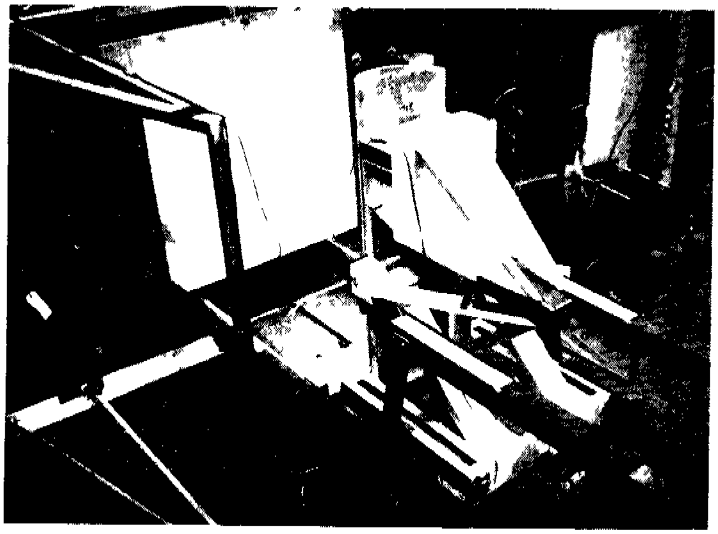
Both "large" radius (nominally 8") and "small" radius (nominally 5") configurations were chosen (see sketch in Figure 6-36). These might represent the upper and lower sections of front contour, respectively. Further, the two radius configurations were combined (co-axially) to obtain a first estimate of the effect of a simple stabilization arrangement (as shown in Figure 6-36).

Neoprene* sheets (1/2" thick) having durometer hardnesses of 30 and 60 were used to represent the skins. The impacting weight was 92.6# for all tests.

*Neoprene was readily available.



(a) TORSO IMPACT FORM



(b) CART AND TEST SPECIMEN

Figure 6-35 PADDING MATERIAL TEST ARRANGEMENT

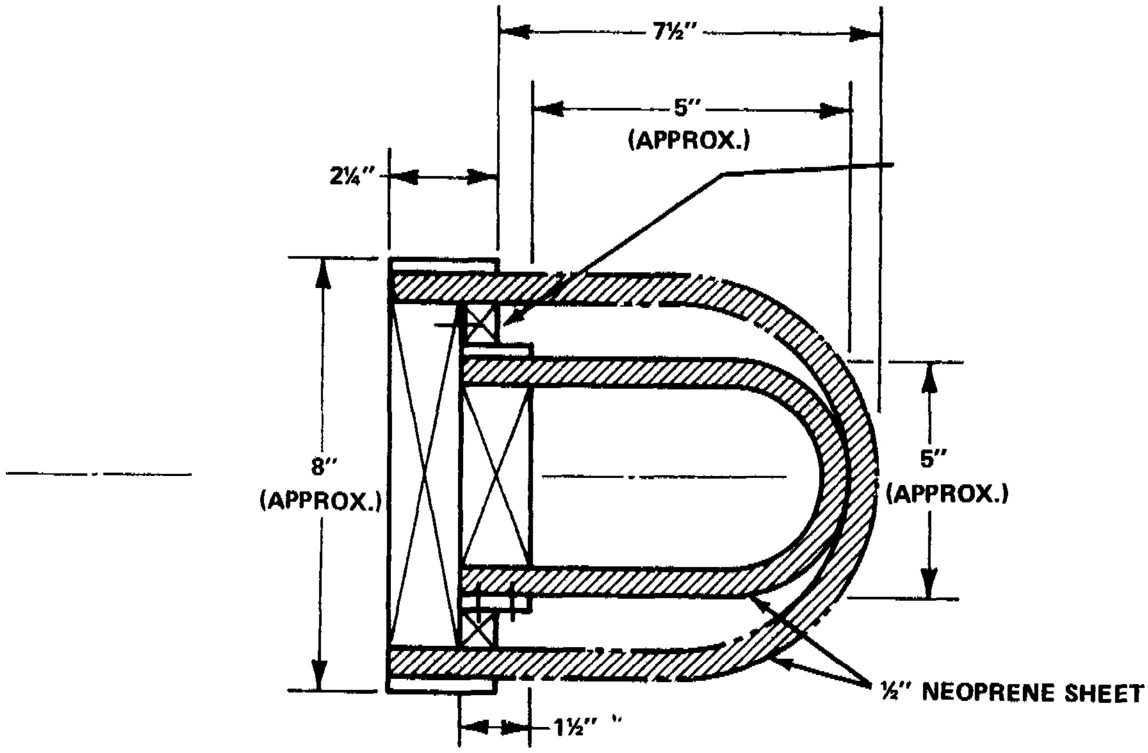


Figure 6-36 Co-AXIAL (NESTED) BUMPER SKIN CONFIGURATION

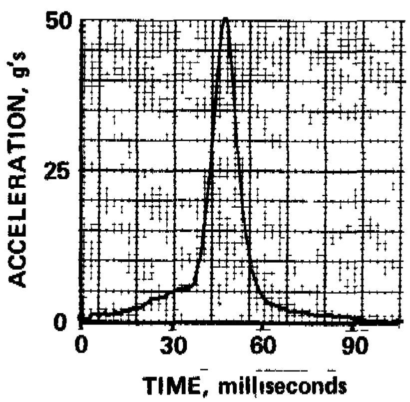
Discussion of the detailed test results (Table 6-12) is not germane to the purpose of the tests--namely, demonstration that practical skin materials would furnish collapse loads sufficiently low to permit contour stabilization with internal stiffeners. Results of importance to the RSV are the following:

- Acceleration levels less than 6 g's were obtained when the skins did not bottom. Therefore, stiffeners can be introduced to raise the levels to 50-60 g's for the upper soft face regions.

- The low accelerations experienced when the skins do not bottom would permit the tailoring of the lower portion of the soft front to keep leg impact forces around 1000#.

- In spite of the inefficient stroke of the skin, the acceleration criterion (less than 60 g's) was satisfied at impact speeds greater than 10 MPH. This matter is developed in the following paragraph.

Shown in the following sketch is the acceleration trace for Run 7. Build-up of the force level reached about 12 g's (at about 35 milliseconds)



RUN 7
IMPACT SPEED = 10.1 MPH
8" BUMPER (½" NEOPRENE SHEET; 60 DUROMETER)
BODY BLOCK WEIGHT = 92.6 #
PENETRATION = 6¾"

Table 6-12

BUMPER SKIN TEST RESULTS

TEST NUMBER	BUMPER CONFIGURATION	NEOPRENE DUROMETER/ THICKNESS	IMPACT SPEED, MPH	MAXIMUM ACCELERATION g's	PENETRATION, INCHES	REMARKS
1	8"	30/½"	3.2	6	6 3/16	BOTTOMED
2	NO DATA					
3	CO-AXIAL	30/½"	4.9	12 1/2	5 3/16	BOTTOMED
4	CO-AXIAL	30/½"	3.2	3	4 5/8	
5	8"	60/½"	4.4	4	5	
6	8"	60/½"	4.8	4 1/2	5 3/16	
7	8"	60/½"	10.1	50	6 3/4	BOTTOMED
8	CO-AXIAL	60/½"	4.9	5	3 5/8	
9	CO-AXIAL	60/½"	4.9	5 1/2	3 1/2	
10	CO-AXIAL	60/½"	10.1	35	4 5/8	BOTTOMED
11	CO-AXIAL	60/½"	15.0	96	5 5/8	BOTTOMED
12	5"	60/½"	3.4	3 1/2	3	
13	5"	60/½"	4.9	4 1/2	4 3/16	
14	5"	60/½"	12.9	95	—	BOTTOMED
15	5"	60/½"	7.2	23	5	BOTTOMED
16	5"	60/1"	5.1	5 1/2	3 3/8	
17	5"	60/1"	10.7	35	5	BOTTOMED
18	5"	60/1"	14.1	66	5 3/8	BOTTOMED
19	CO-AXIAL	30/½"	5.0	13	5	BOTTOMED
20	CO-AXIAL	30/½"	3.2	3	4 1/2	
21	CO-AXIAL	30/½"	3.0	2 1/2	4 3/8	

before bottoming of the skin occurred. The 50 g level was achieved by compressing the neoprene skin itself. Acceleration margin available for insertion of ribs corresponds to the difference between the unbottomed skin-developed 12 g's and the allowable 60 g's. Therefore, development of the stabilized skin configuration (discussed in a previous section) is deemed to be feasible. Ideally, the ribs (and skin contour effects) would be made to produce a square wave arresting acceleration of around 60 g's at an impacting speed of about 22 MPH (for the upper portion of the soft face front).

The lower portion of the soft face contour would impact pedestrian legs and, hence, would be accelerating a mass lower than that of the test block. We note that 12 g's were applied just before the bottoming of the bumper in the Run 7 test just described. Corresponding force level is about 1100 lbs.--near the limit of strength of lower legs. Contour refinement (recall the test bumper was essentially a half circle) and skin thickness adjustment would still allow addition of bumper stabilizing ribs even in this area.

In summary, the limited bumper tests performed suggest that a soft face system is feasible. Low collapse forces suitable for pedestrian protection can be achieved within the constraint that the structure be stable. Claims for the system performance cannot be made, however, since field data on such systems are not available.

6.3.5 Crashworthiness

The most important and challenging element within the RSV program is the development of a highly advanced crashworthiness system. When developing the crashworthiness specifications, an attempt was made to insure that desirable flexibility for appropriate design trade-offs would be maintained in future phases of the program. It is recognized that considerable progress has been made in the development of crash energy management during the past few years. Furthermore, that this progress is continuing and because the RSV development and build phases will span the next three years, the specifications should provide sufficient latitude so as to take advantage of possible future progress. On the other hand, the specifications must insure that the RSV reflects important improvements over the typical crash performances of present cars.

The RSV structure must be a system which is well integrated in the sense that various structural elements participate in a number of different impact types. This theme is developed in Volume III of this report. Table 6-13 illustrates the various structural zones and nominal characteristics anticipated for each zone. It is intended that the RSV structural design will generally follow guidelines indicated in Table 6-13. In this section of Volume IV we present and discuss the structural concepts proposed to accomplish the objectives delineated in Table 6-13.

Before discussing major structural modifications, we will examine the base vehicle structural components and identify those parts which are not likely to be changed, those parts which will be of the same shapes but of different materials, and finally those parts or areas of the vehicle structure which will require major redesign. Figure 6-37 is a C-6 base vehicle exploded view indicating the major structural parts. Those parts indicated as normal line weight unshaded will be carried over from the existing base vehicle without any changes. Parts shown with medium shading are considered likely candidates for HSLA steels. These particular components are the major load carrying elements of the structure in the crash environment and as such would

Table 6-13

RSV EXTERIOR CHARACTERISTICS

IMPACT DIRECTION	ZONE	MAJOR CONSIDERATION	RANGE (NOMINAL)		
			CRUSH (IN)	ACCELERATION (G's)	ENERGY ABSORPTION (x 1000 FT LBS)
FRONT	I_f	PEDESTRIAN PROTECTION & MIN. VEHICLE DAMAGE	4-6	6-10	7-10
	II_f	SIDE & REAR COMPATIBILITY WITH OTHER VEHICLES	6-10	15-20	40-55
	III_f	OCCUPANT PROTECTION FRONTAL COLLISIONS	18-22	30-40	150-200
REAR	I_r	MIN VEHICLE DAMAGE	3-4	4-8	2-3
	II_r	OCCUPANT PROTECTION REAR COLLISIONS	20-26	12-25	70-95
SIDE	I_s	MIN VEHICLE DAMAGE & VISIBILITY	1/2-1	–	–
	II_s	OCCUPANT PROTECTION SIDE COLLISIONS	8-12	20-25	35-55
ROLLOVER	–	OCCUPANT PROTECTION	4-6	–	–

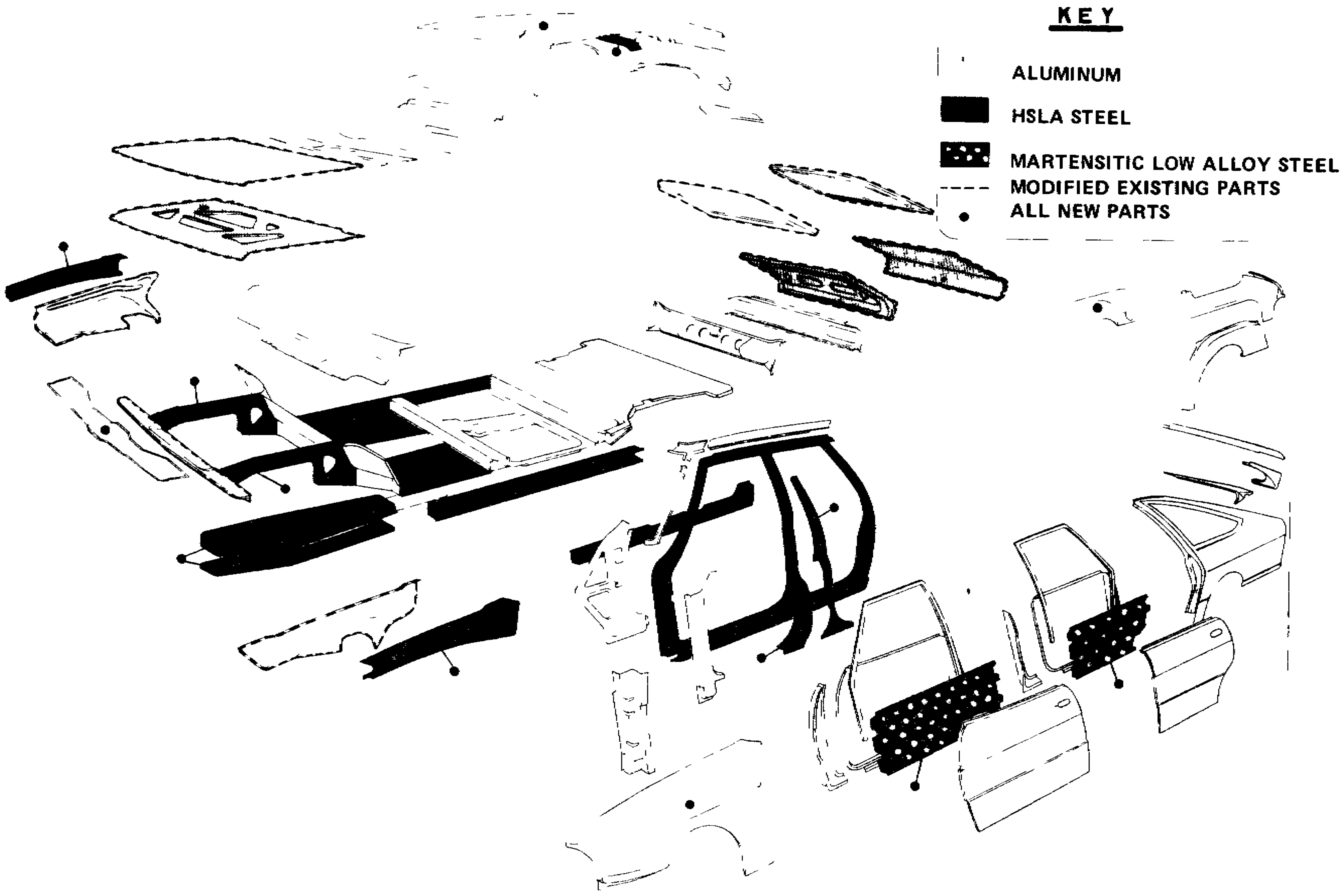


Figure 6-37 EXPLODED VIEW OF C-6 BASE VEHICLE INDICATING MATERIAL SUBSTITUTIONS AND/OR REDESIGN

exhibit substantially improved structural crashworthiness performance if constructed of the stronger HSLA steels which are compared with mild steel in Table 6-14. These possible HSLA components include the front half of the floorpan, the compartment floor side rails, perhaps the stub frame rails, the B-pillars, and the roof beam. In addition, parts in Figure 6-37 with light shading are possible candidates for aluminum to reduce vehicle weight thereby improving vehicle fuel economy. The use of a lightweight alloy will probably be limited to the hood and rear deck lids because of material recycling considerations.* The necessity of separating various automotive materials during salvaging operations precludes mixing metals in a highly integrated structure but separate items such as hoods and trunk lids may be easily separated from the vehicle with minimal labor prior to scrap processing. The dark shaded door beams shown in Figure 6-37 will be made from Martensitic low alloy steel and will be bonded to the door skin. These beams are discussed later in this section.

Structural redesign, indicated in Figure 6-37 by either a dashed outline or a black dot depending on the degree of redesign, that has been considered to achieve the desired RSV crash performance includes such parts as the B-pillars, addition of a roof beam, the compartment side doors, the center tunnel position of the compartment floor, the frontal sheet metal and the front rails. These redesigns include shape changes and in at least some instances, the use of HSLA steels. These structural modifications will now be discussed in some detail in the next several subsections. For purposes of

* We note here that our approach essentially precludes a number of vehicle weight reduction schemes presently under consideration for automobiles using lightweight alloy metals. For example, currently a major domestic automobile manufacturer is using aluminum hood inner panels with mild steel hood outer panels. This practice if widely applied throughout the industry and with many more body components could have disasterous ramifications of future metal scrap recovery because dissimilar metals could not easily be separated. The point is that we feel lightweight metal alloys do have potential for increased application in the automobile; but, such applications have implications that extend well beyond strict consideration of only weight reduction requirements.

Table 6-14
COMPARISON OF THE MECHANICAL PROPERTIES OF CARBON STEELS AND HSLA

*Typical mechanical properties of carbon steels**

	AISI Type											
	1015/1020/1022			1035/1040			1045/1050			1095		
	Hot Rolled	Cold Drawn	Annealed (1,600F)	Hot Rolled	Cold Drawn	Quenched and Tempered†	Hot Rolled	Cold Drawn	Quenched and Tempered†	Hot Rolled	Cold Drawn and Annealed (1,480F)	Quenched and Tempered†
Yield strength (10^3 psi)	30	51	43	42	71	63-96	49	84	68-117	66	76	80-152
Tensile strength (10^3 psi)	55	61	60	76	85	96-130	90	100	105-137	130 min	99	130-216
Impact strength, Izod (ft lb)	85	—	80	36	—	36-72	23	—	16-53	3	2	5-6
Creep strength, 0 0001%/hr (10^3 psi) 800F	—	12 3	—	—	—	—	—	—	—	—	—	—
900F	—	5.7	—	—	—	—	—	—	—	—	—	—
1 000F	—	2 6	—	—	—	—	—	—	—	—	—	—
Elongation in 2 in (%)	25	15	38	18	12	17-24	15	10	25-15	9	13	10-84
Modulus of elasticity (10^6 psi)	29-30	29-30	29-30	29-30	29-30	29-30	29-30	29-30	29-30	29-30	29-30	29-30

*Approximate properties based on 1-in. cross section Larger sections have lower mechanical properties. These steels generally are not selected for fatigue applications so data is not available Properties vary with quench medium and temper time and temperature Values shown represent the range of properties available

Typical mechanical properties of HSLA steels

	Semikilled or Killed	Semikilled or Killed—Improved Corrosion Resistance	Semikilled or Killed	Inclusion Control—Improved Formability, Killed	Semikilled or Killed	Semikilled or Killed	Inclusion Control—Improved Formability, Killed	Semikilled or Killed	Semikilled or Killed	Inclusion Control—Improved Formability, Killed	
Specifications	SAE J410C ASTM A607	ASTM A606 Type 2 & 4 (weathering)	ASTM A607 SAE J410C	none	ASTM A607 SAE J410C	ASTM A607 SAE J410C	none	ASTM A607 SAE J410C	ASTM A607 SAE J410C	none	
Composition	Cb and/or V	(Proprietary) Cu Cr C Mn Ni P & other additions	Cb and/or V	(Proprietary) Cb Ti Zr Si N V & others			(Proprietary) Cb V Zr Si N Ti & others	Cb and/or V	Cb and/or V	Cb V Ti Zr Si N	
Yield strength (10^3 psi)	45	50	50	50	55	60	60	65	70	70	80
Tensile strength (10^3 psi)	60*	70	65*	60	70*	75*	70	80*	85*	80	90
Cold bending†	1t	1t	1t	0t	1½t	2t	0t	2½t	3t	1t	1t
Elongation in 2 in (%)	25	22	22	24§	20	18	22§	16	14	20‡	18‡

Adding 0 02% (minimum) Cu to HSLA steels provides approximately two times the atmospheric corrosion resistance of carbon steel
*Reduce by 5 000 psi when lower carbon composition is required
†ASTM A370 longitudinal test specimen up to 0 229 in inclusive For transverse bending use values ½ to 2t higher or 0 to ½t higher for improved formability grades
§Subtract 2% for thicknesses 0 097 in or less

discussion, the modifications will be segregated according to their primary function; frontal, side, rear and rollover occurrences. However, the multiple payoff of some modifications, such as the possible benefits of improved side structures in both side and frontal impacts and between vehicle side and frontal structures is recognized and will be brought out in the ensuing discussion. In addition, results of a computer simulation using the BASHSIM program will be presented and discussed to indicate the approximate magnitude of the changes needed in the various vehicle structural component force-deflection characteristics necessary to attain the desired crash performance.

Front Structure Modifications

The first six inches of the vehicle front structure, identified as Zone I_f in Table 6-13 is intended to provide low speed pedestrian impact protection and minimize vehicle damage. This element will be an add-on to the base vehicle consisting of an integrated bumper/soft face front end as discussed in Section 6.3.4

Zone II_f, Table 6-13, is designed to provide crush force compatibility between vehicle front and side structures and will be physically achieved with the base vehicle by modifying the front frame rails and sheet metal. The front frame rails are defined as the rails from the engine cross-member forward, consistent with the BASHSIM model definitions shown in Figure 6-17.

Zone III_f, defined in Table 6-13, is intended to provide high speed frontal impact protection and the deceleration level selected for this zone is based on generally accepted acceleration limits for occupant survivability assuming adequate restraint performance.

Zone III_f crash performance is primarily determined by the front sheet metal and the portion of the frame rails between the engine and compartment, defined in Figure 6-17 for the BASHSIM model as the rear rails. In order to achieve the Zone III_f performance desired in the RSV, a modification to the compartment floor in the center forward region has been investigated to supplement the frame rails and the sheet metal. This tunnel region modification consists of an extension of the compartment tunnel forward into the engine compartment to within one inch of the engine. This extension is envisioned as being rectangular in cross-section and containing cutouts or "darts" to insure a compression collapse under crash loading. BASHSIM simulations, to be discussed shortly, indicate that the static force level for this tunnel extension need be approximately 25,000 lbs which, for example, the work in Ref. 6-20 suggests would require a rectangular section 2-1/2" x 4" x 1/8" thick if made from mild steel and proportionately less if made from HSLA steel. This extended tunnel region would probably be tied into the compartment floor by mounting it over the existing tunnel and carrying the section aft to butt against the HSLA steel cross sill which will now be effective in frontal as well as side impacts.

In order to approximately ascertain the changes needed in the base vehicle frontal structure to produce the desired frontal crash pulse consisting of Zones I_f, II_f and III_f, a computer simulation was performed using the BASHSIM model. Simulation of the extended tunnel region using the BASHSIM model was accomplished by using the driveline component of the model as the load path. The RSV, being a front wheel drive automobile, has no driveline load path to the compartment, hence, this model component is available to simulate the tunnel region. Figure 6-38 shows the assumed force-deflection curve that was used as input to the BASHSIM program. The component was assumed to have one inch of deflection at zero force level to simulate slack in the system followed by a rapid rise to 25,000 lbs. over the remainder of the total deflection of 18 inches. The slack in the system results from the engine mount which, it is anticipated, will connect the engine to the tunnel.

The other structural modifications assumed for the simulation are as indicated in Figures 6-39, 6-40 and 6-41 for the front frame rails, rear frame rails and front sheet metal, respectively. In each of these figures the production Simca static crush force-deflection characteristic is included

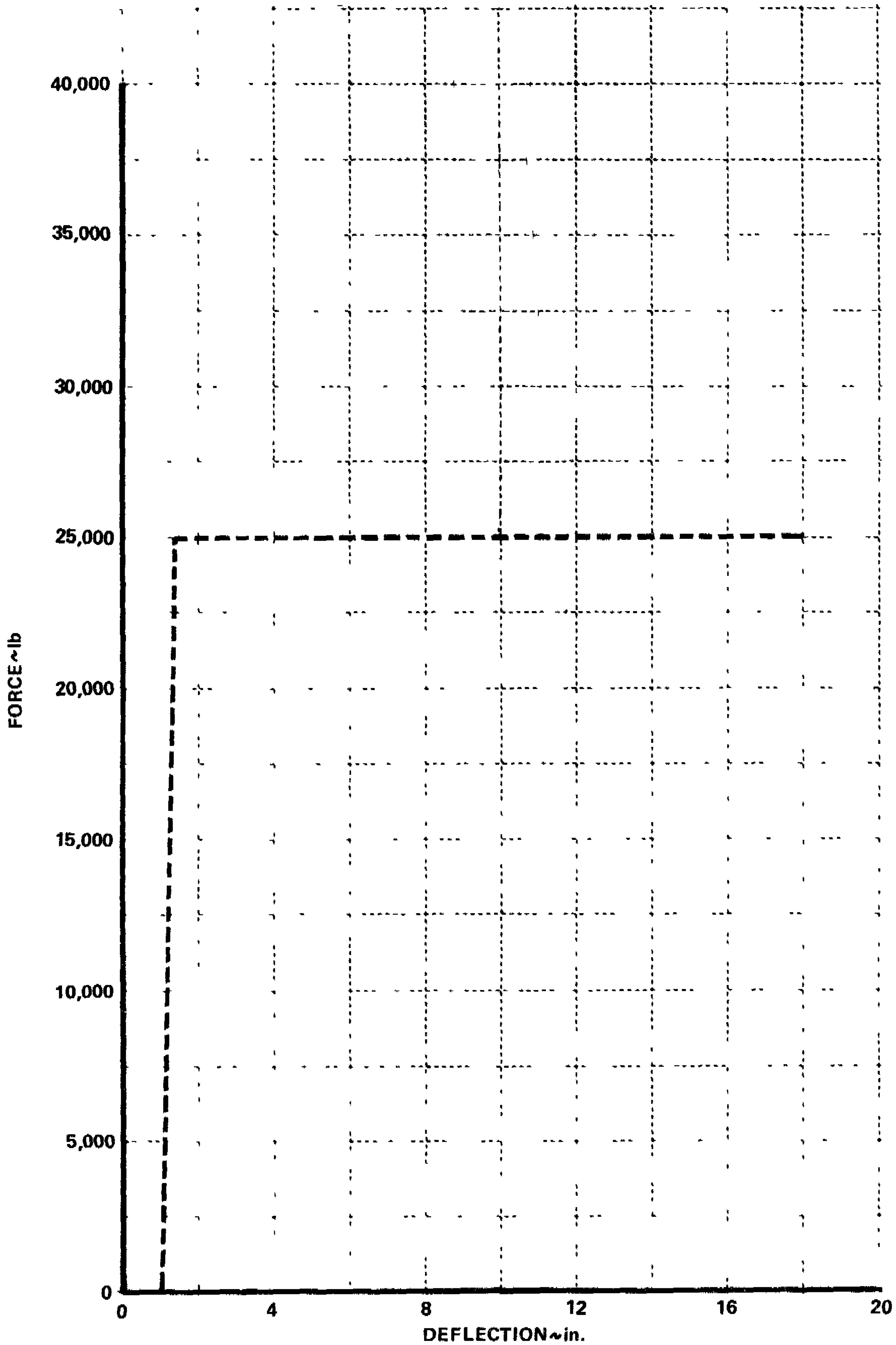


Figure 6-38 COMPARTMENT FLOOR TUNNEL REGION FORCE-DEFLECTION INPUT TO BASHSIM PROGRAM FOR MODIFIED SIMCA

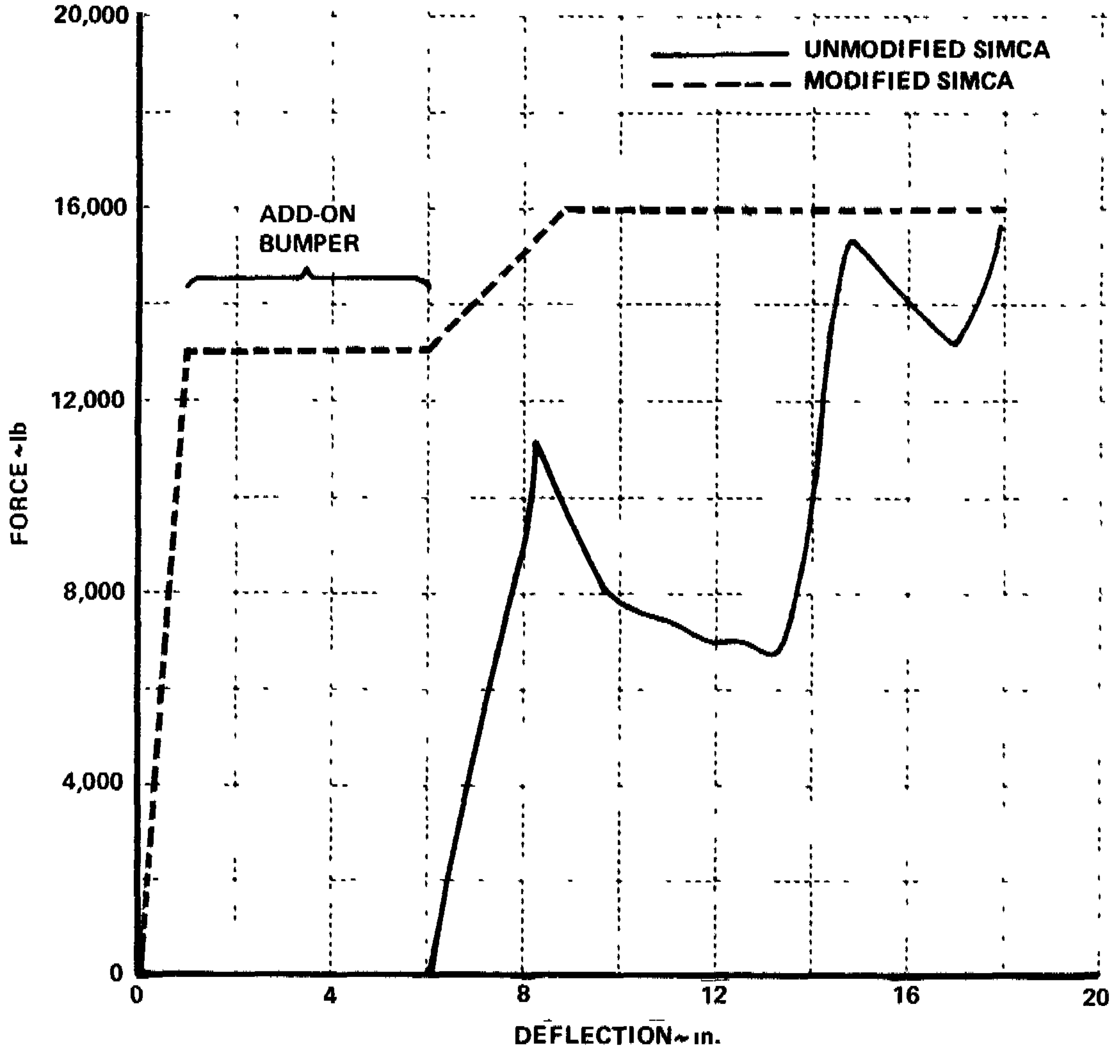


Figure 6-39 MODIFIED AND UNMODIFIED FRONT FRAME RAIL USED IN BASHSIM PROGRAM

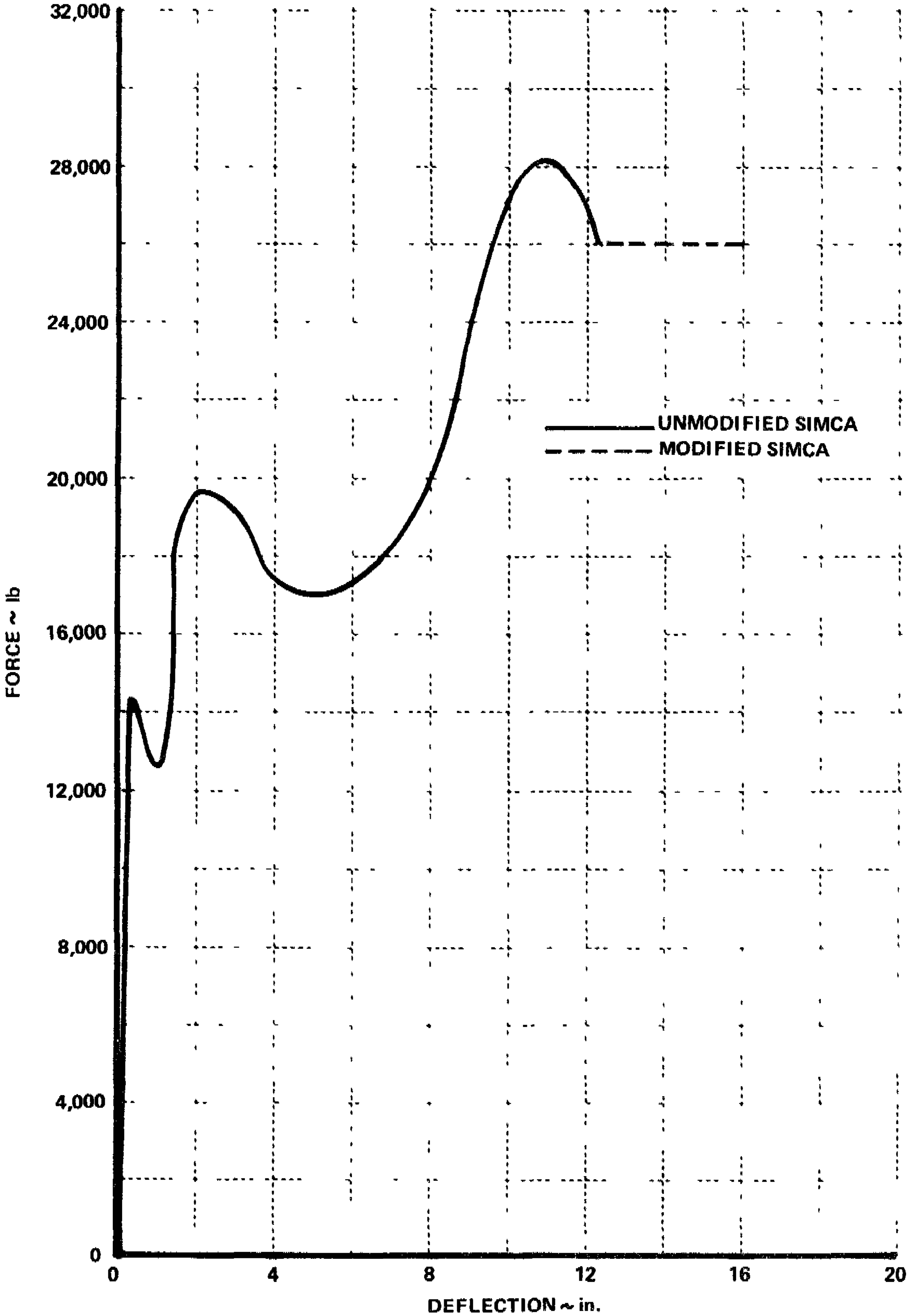


Figure 6-40 MODIFIED AND UNMODIFIED REAR FRAME RAILS USED IN BASHSIM PROGRAM

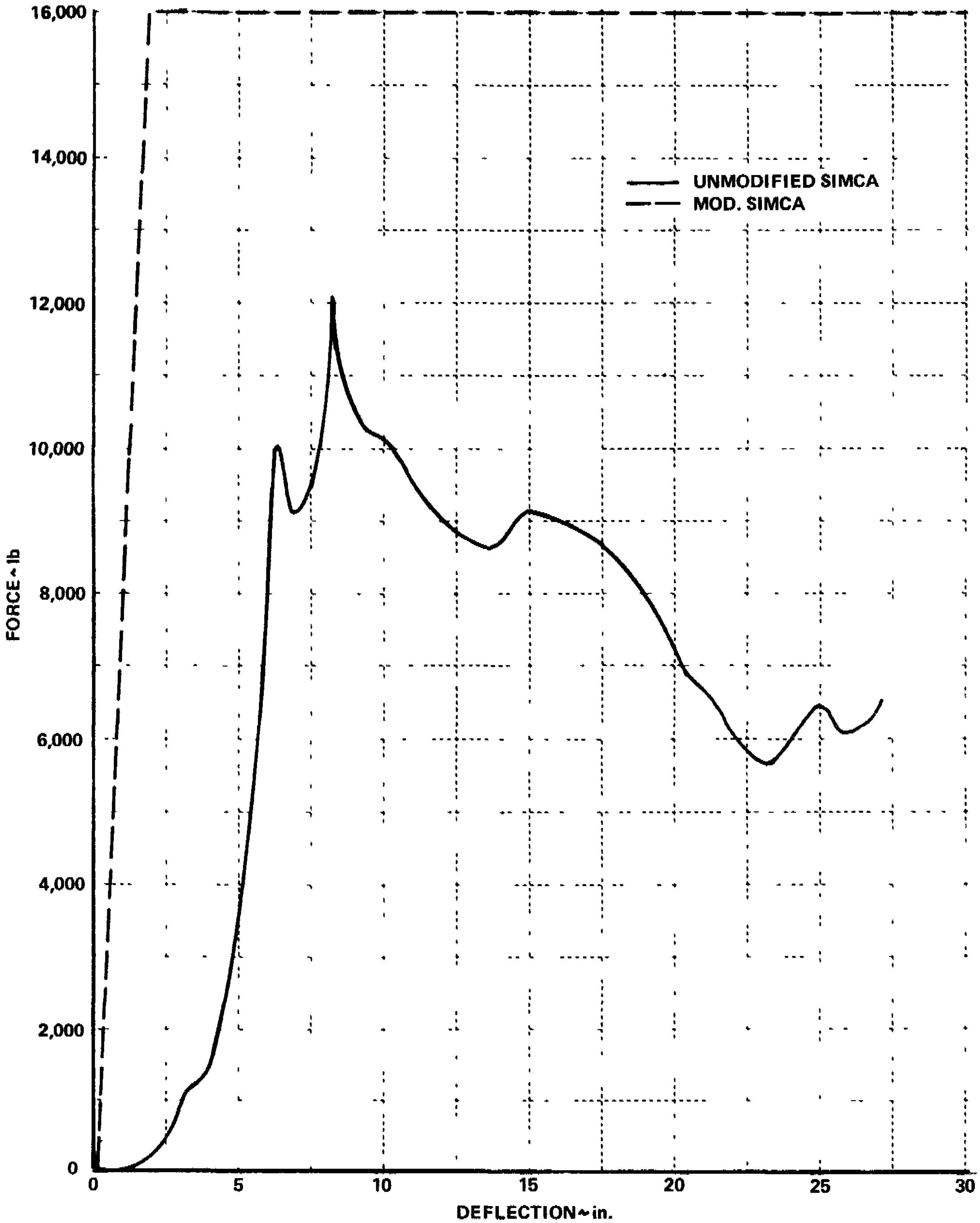


Figure 6-41 MODIFIED AND UNMODIFIED FRONTAL SHEET METAL USED IN BASHSIM PROGRAM

to indicate the base vehicle performance which is being modified. The front frame rails, Figure 6-39, have been extended approximately 6 inches for modeling purposes to permit Zone I_f to be incorporated in the initial part of the rail collapse. This is an artificial but acceptable method of including Zone I_f, which in the vehicle will be an add-on bumper system extending ahead of the front rails, in this model without increasing the number of structural components in the model. The initial 6 inches of front frame rail collapse represents Zone I_f. The rear frame rails, component 2 in the BASHSIM model have not been modified in strength (see Figure 6-40) for the simulation but have been lengthened 3.5 inches to reflect a vehicle lengthening which is under consideration. The sheet metal static force-deflection characteristic, shown in Figure 6-41, indicates a lengthening which includes some of Zone I_f and the increased rear frame rail length. The crushing force level has also been increased rather substantially. It is anticipated that the sheet metal will be strengthened in the RSV by incorporating stiffeners into the structure at the junction between the inner and outer fender panels. The remaining components of the model, engine mounts and radiator remain the same as those shown in Figure 6-18 for the unmodified base vehicle.

Using the modified static force-deflection inputs indicated above in the BASHSIM model resulted in the vehicle deceleration waveforms shown in Figures 6-42-6-47 for barrier impact speeds from 10 to 50 MPH. Figures 6-42 and 6-43 indicate that Zone I_f performance, 10 g or less, for low speed pedestrian protection and vehicle damage minimization is about as desired. It does appear that the length of this zone is a little shorter than desired above 10 MPH. Figures 6-43, 6-44 and 6-45 indicate that Zone II_f, required for side impact compatibility is satisfactorily achieved for 20 to 40 MPH impacts while Figure 6-46 shows that the higher energy crash performance nearly achieves the desired goal. It does appear from Figures 6-45 and 6-46 that the extent of Zone II_f may be a little larger than desired and may require correction during the "fine tuning" of the actual structure during final design and development. Figure 6-47 indicates the time history of the deceleration waveform. The 50 MPH simulation resulted in approximately 6 inches of compartment intrusion

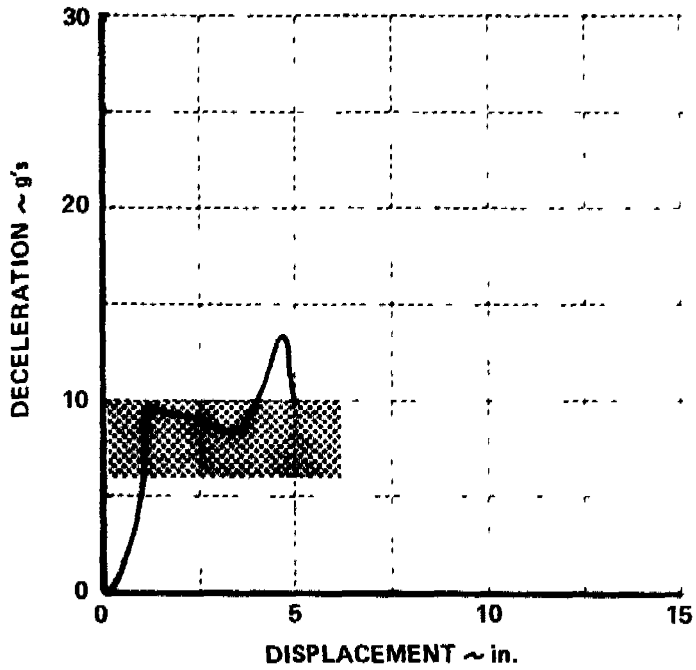


Figure 6-42 MODIFIED BASE VEHICLE DECELERATION vs DISPLACEMENT FOR A 10 mph BARRIER IMPACT

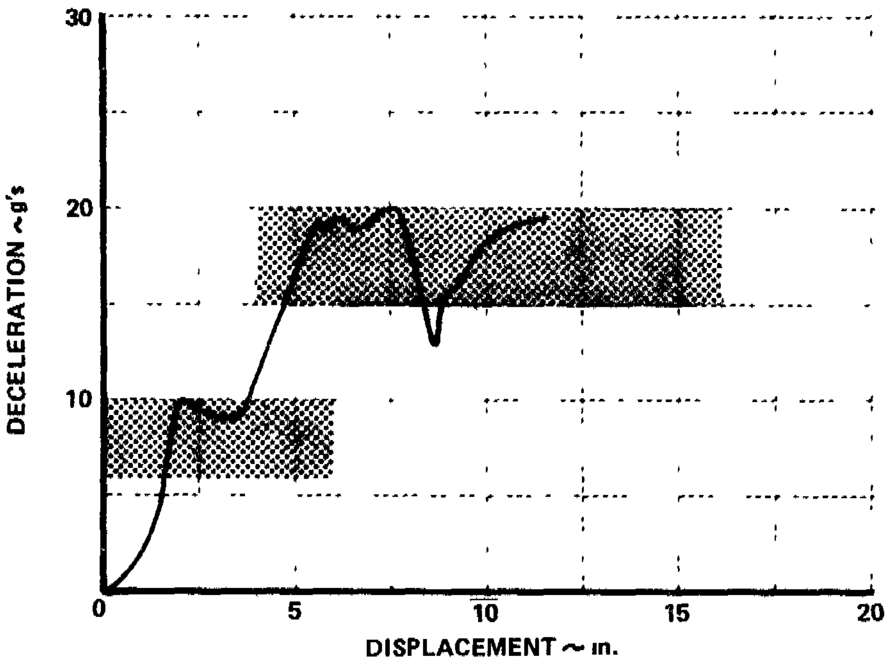


Figure 6-43 MODIFIED BASE VEHICLE DECELERATION vs DISPLACEMENT FOR A 20 mph BARRIER IMPACT

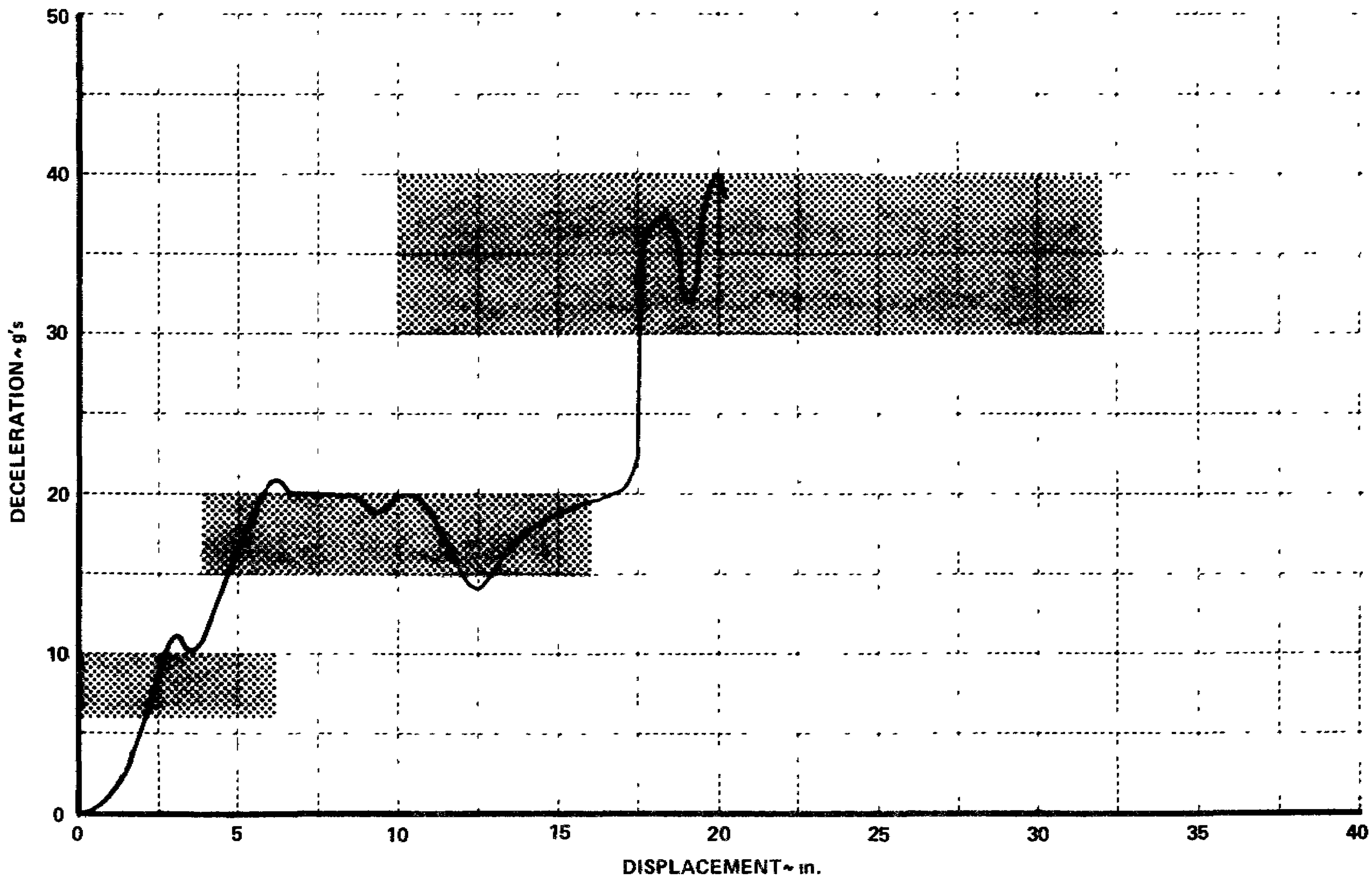


Figure 6-44. MODIFIED BASE VEHICLE DECELERATION vs DISPLACEMENT FOR A 30 mph BARRIER IMPACT

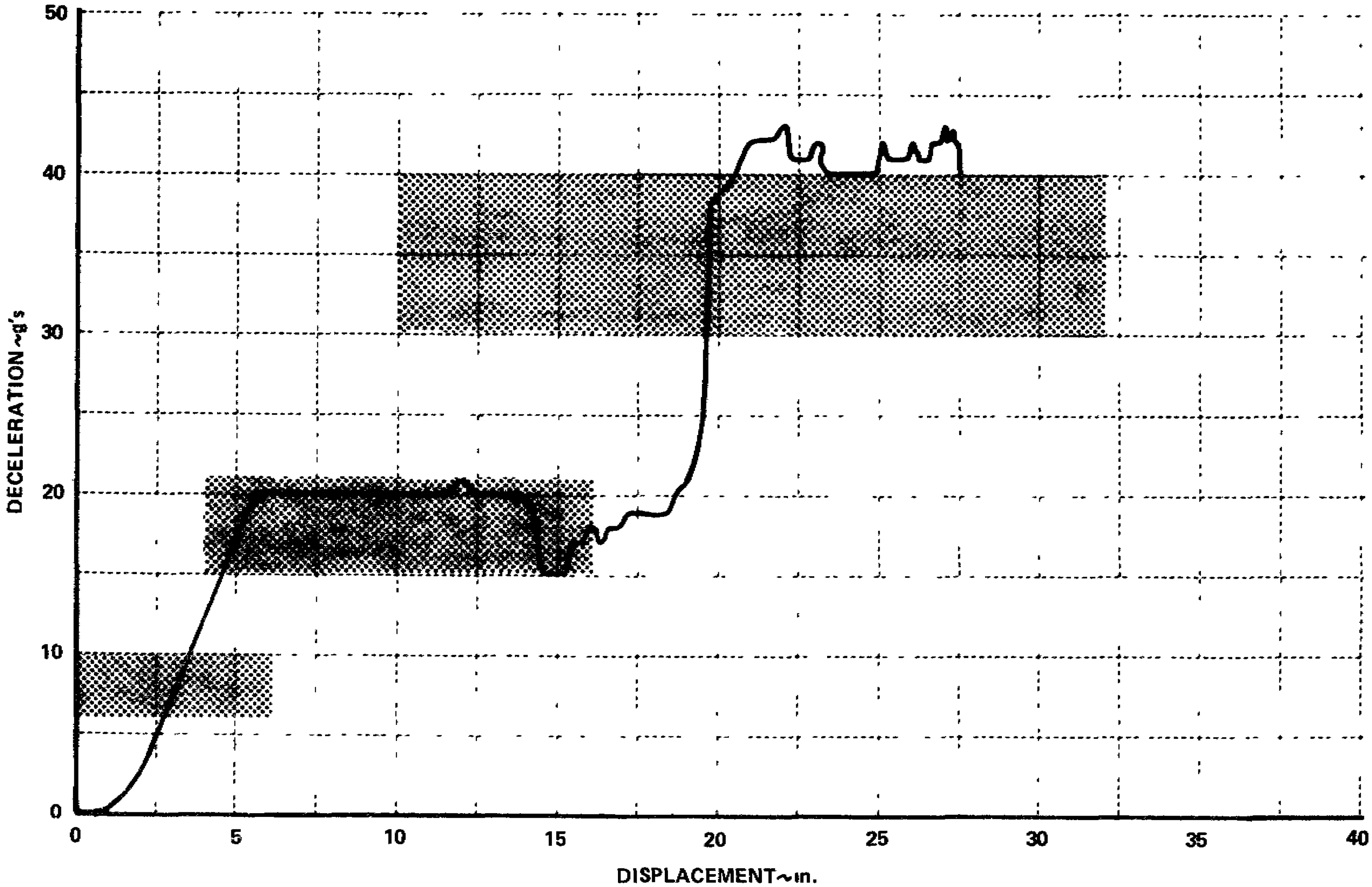


Figure 6-45 MODIFIED BASE VEHICLE DECELERATION vs DISPLACEMENT FOR A 40 mph BARRIER IMPACT

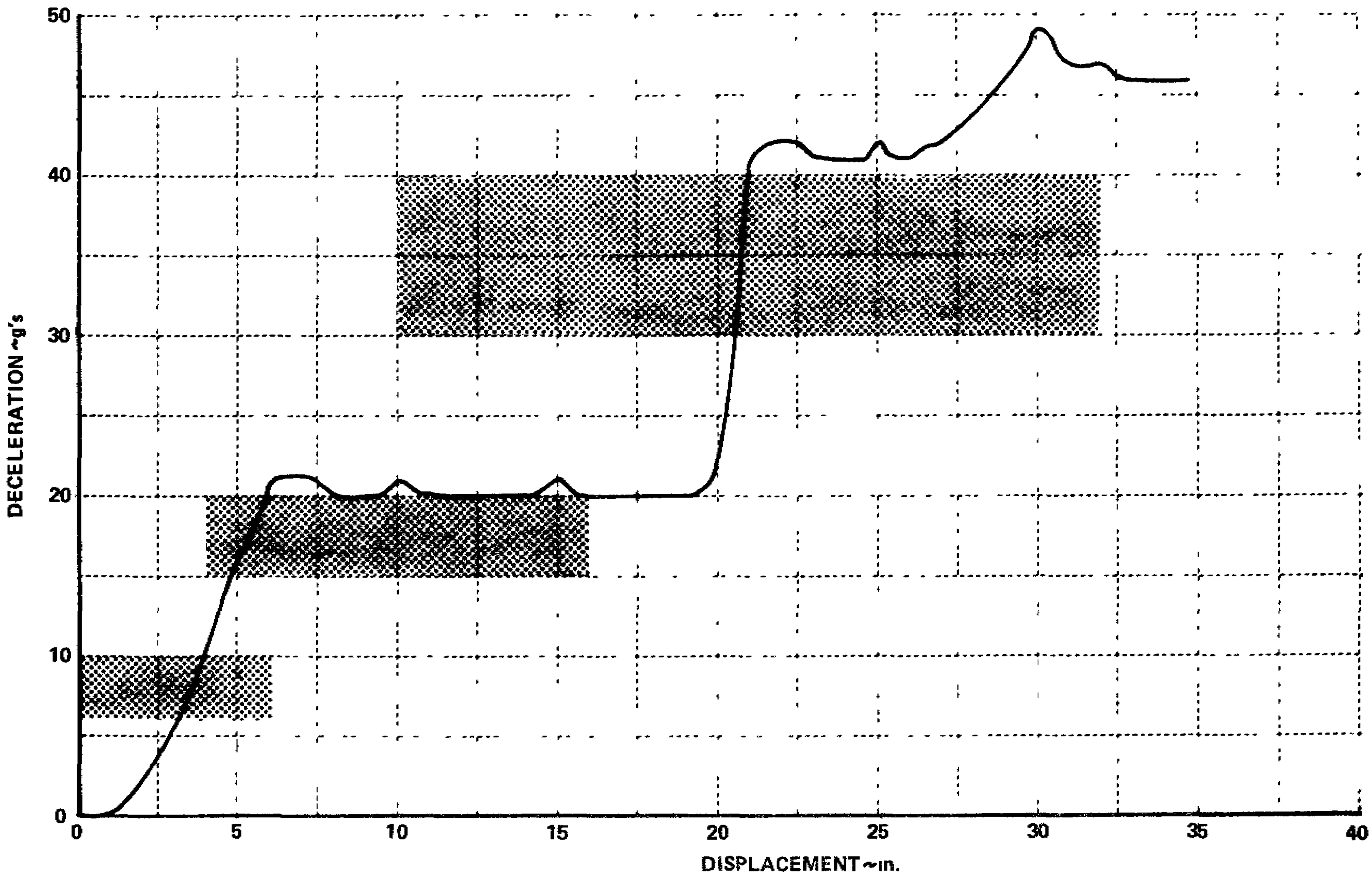


Figure 6-46 MODIFIED BASE VEHICLE DECELERATION vs DISPLACEMENT FOR A 50 mph BARRIER IMPACT

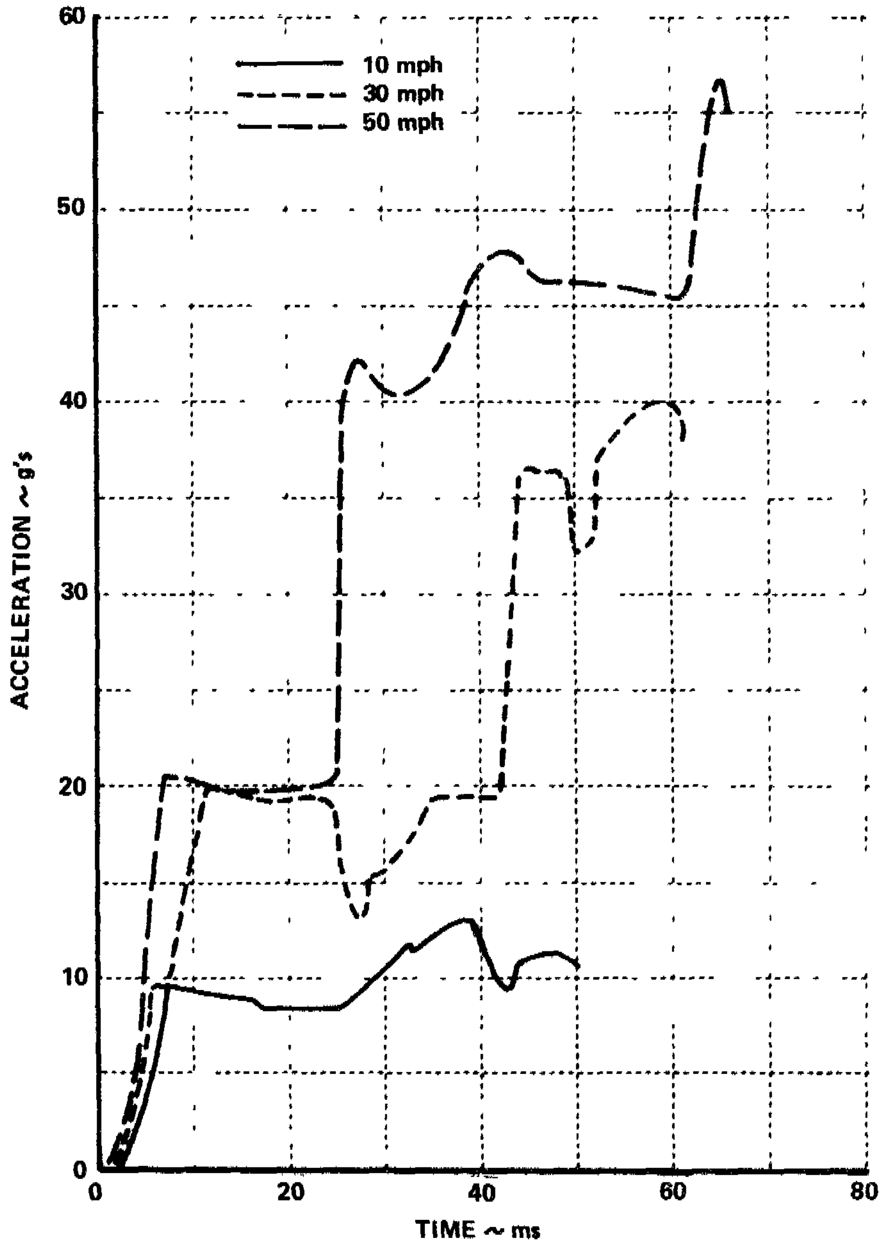


Figure 6-47 ACCELERATION TIME HISTORIES FOR SIMULATED RSV STRUCTURE AT 10, 30, AND 50 mph BARRIER IMPACT VELOCITIES

which is considered acceptable for a belt restraint system but not for an air bag (with energy absorbing bolster) system. Further discussion of the ramifications of restraint system choice on structural requirements is included in Section 6.3.6.

The important conclusions to be drawn from this preliminary simulation study is that it appears that neither major weight additions to the base vehicle nor major design difficulties will be experienced in achieving the desired RSV frontal crash performance.

Side Structure Modifications

The side structure modification consists primarily of strengthening the B-pillar to achieve compatibility with the Zone II_f 20 g deceleration structure. In addition, the passenger doors will be reinforced, not particularly for side impact protection, but to provide a longitudinal load path along the sides of the vehicle for higher speed frontal impacts. It is anticipated that this door strengthening will be accomplished by bonding corrugated high strength martensite steel (see Table 6-15) to the inner surface of the door outer skin as indicated in the exploded view of Figure 6-37). These door columns will be designed to butt against substantial portions of the vehicle pillars to provide the longitudinal load paths. Rear door columns may not be necessary if the B-pillars are strong enough to react the longitudinal loading of the front door columns. Not only will the door columns reduce compartment deformation in frontal collisions but then also will help maintain the door system integrity, allowing normal occupant egress from the vehicle following crash impacts. The door columns will, of course, provide some additional side impact protection in the bending mode but this is coincidental to their primary function as columns reacting vehicle frontal loads.

The primary element providing side impact protection is the B-pillar which will be designed to provide a vehicle acceleration of approximately 25 g,

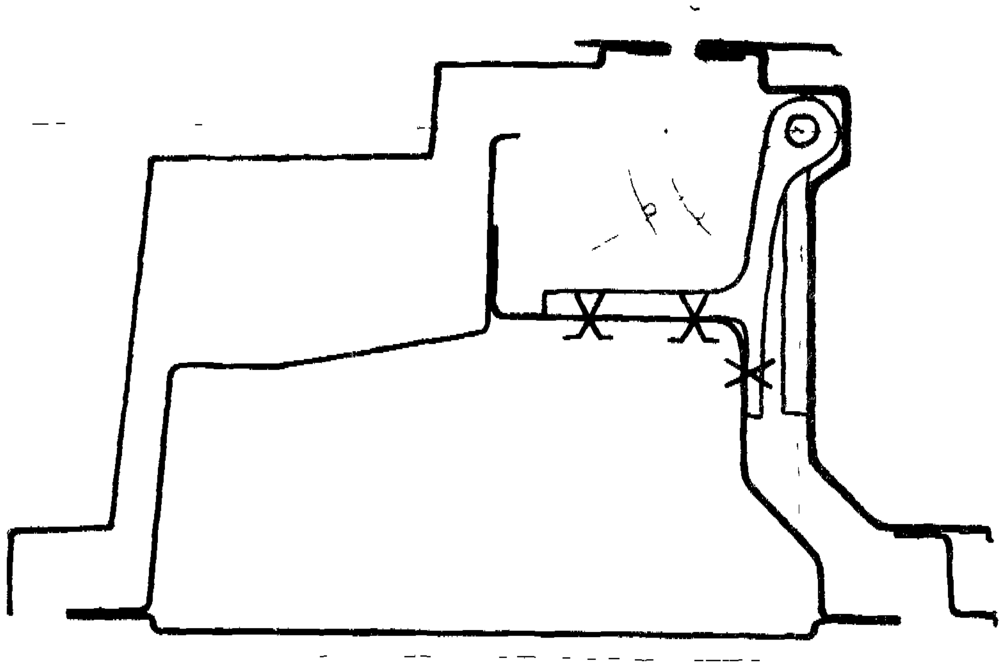
Table 6-15

TYPICAL MECHANICAL PROPERTIES OF IRON-BASED SUPERALLOYS

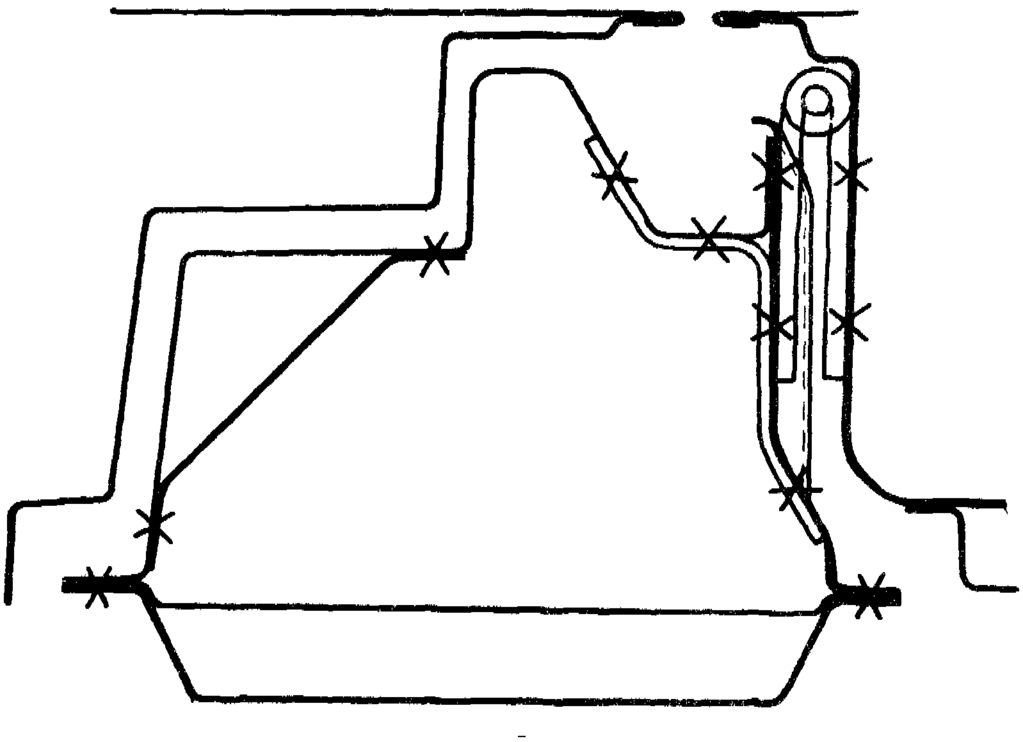
	Martensitic Low Alloy		Martensitic Secondary Hardening		Martensitic Chromium		Semiaustenitic		Austenitic Hot/Cold Worked		Austenitic	
AISI Grade	601	604	610	613	616	619	633	635	650	653	660	665
Typical Designation	17 22A	Chromalloy	H-11	M-50	422	Lapelloy	AM350	Stainless W	16-25-G	17-24 CuMo	A-286	W-545
Yield strength (10³ psi) 70F	100	95-108	100-240	335	125-175	85-220	60-175	215-290	50-100	40-90	95	123-142
1 000F	54	85	140	250	126	85	108	37 50	33	29	88	120
Tensile strength (10³ psi) 70F	120	125-138	135-310	410	150-240	125-250	160-205	220-225	110-140	86-112	146	176-187
1 000F	77	110	180	309	170	95	160	75-80	90	65	131	154
Impact strength, Charpy (ft lb) 70F	—	—	10-32	—	10-38 (T700-1400)	—	14	4 106	15	8-26	41-60	—
Fatigue endurance limit (10³ psi)	—	—	130 (at 260 t s)	—	90-110 (T980-1100)	—	70-100	54-96	—	—	—	—
Creep strength, 0 0001 % hr at 1 000F (10³ psi)	—	—	—	—	—	—	—	—	26	10	—	—
Elongation in 2 in (%) 70F	30	7	3-17	2	16-19	10-20	12 38	1 5	20-45	30-45	25	19
1 000F	29	—	11	6	16	15	9	47 58	58	37	19	13
Modulus of elasticity (10⁶ psi)	30 8	31 7	30 5	29 5	29 0	30 0	29 4	30 2	28 5	28 0	28 8	28 4
Rupture strength, 100hr 1 000F (10³ psi)	49	75	95 115	—	58	65	103	32	78	48	100	120

Zone II_s in Table 6-13, allowing for compatibility with Zone II_f of the RSV front structure. This front-to-side compatability insures that substantial collapse will occur in the front structure of the impacting RSV prior to the deformation of the target RSV side structure. It is anticipated that the B-pillar will be constructed of HSLA steel and will be substantially larger in cross-section than the current base vehicle pillar. A simple calculation indicates the order of the strength needed in the B-pillar to achieve sufficient side impact protection. Assuming a gross vehicle weight of 3000 lbs., and a desired B-pillar collapse strength which in conjunction with the other elements of the side structure will produce a collapse force level equivalent to 25 g to insure that Zone II_f of the striking car is deformed before Zone II_s of the struck car, results in a total side force of 75,000 lbs. If one-half of this total side force must be sustained by the B-pillar and the pillar ends are assumed to be fixed, a straightforward calculation shows that the maximum plastic section modulus needed in the pillar is 2.6. This plastic section modulus is approximately equivalent to that provided by a 4 x 6 x .060 wall rectangular section of HSLA steel, indicating that a pillar of the desired strength is certainly achievable.

In addition to providing a much stronger B-pillar for the RSV, certain geometrical changes are also contemplated to further improve the crash performance over that of the base vehicle and present state-of-the-art vehicle in general. The B-pillar will be designed so that its outer surface is as close as feasible to the outer surface of the car. During side impacts the pillar would then be loaded early in the crash sequence to make maximum use of the limited deformation space available in these types of collisions. Another feature to be incorporated into the new B-pillar design is the provision of suitable load bearing surfaces for the door columns discussed earlier. These bearing surfaces are envisioned as flat surfaces in the B-pillar to react the door column loads as shown in the cross-section sketch of Figure 6-48, which indicates the current production B-pillar cross-section and a possible design for the new pillar.



a) EXISTING C-6 B-PILLAR CROSS-SECTION



b) POSSIBLE NEW B-PILLAR DESIGN FOR RSV

Figure 6-48 COMPARISON OF EXISTING AND NEW B-PILLAR CROSS-SECTIONS

Rollover

It is anticipated that the C-6 base vehicle with the improved B-pillars will exhibit satisfactory rollover performance with little additional modification. As part of the strengthening for side impacts, a HSLA steel roof cross-member between the upper ends of the B-pillars will be added to the vehicle. This cross-member and B-pillar structure is anticipated to provide satisfactory rollover protection for the vehicle occupants.

Rear Impact

As has been emphasized elsewhere in this report, the primary emphasis in crashworthiness development has been placed on the front end of the vehicle because it is in this region that the highest payoff is achieved. The rear impact is one example of this payoff inasmuch as rears are almost exclusively impacted by other vehicle fronts. If the front of the car has been suitably designed then a multiple payoff is realized, i.e., both frontal and rear impacts are favorably affected. With this philosophy in mind and the realization that even state-of-the-art vehicles possess adequate rear end crashworthiness, no major structural changes are anticipated in the rear.

The primary consideration in rear end crash protection is fuel system integrity and the C-6 base vehicle, because of its front engine front wheel drive configuration, permits the optimum arrangement for fuel tank protection; namely, between the car wheels underneath the underbody structure.

6.3.6 Interior and Restraint Systems

The safety afforded car occupants depends not only on the compartment integrity and acceleration environment provided by the vehicle structure but also on the protective devices within the passenger compartment. From a theoretical standpoint any device within the compartment which loads the occupant during collisions could be considered part of the restraint system. For the purposes of this discussion, however, we have elected to focus separate attention on specific interior components and the primary restraint system. In this context candidate primary restraint systems for the RSV include either an advanced belt or collapsible dash air cushion systems.

Interior Components

Restructuring the C-6 into the RSV will likely include addition of padding to pillars, headers, etc.; but, because of the stringent side and rear impact requirements the main components of concern will be the panels and the front seats. Possible changes to these components are considered below.

As a result of previous and current Calspan research for NHTSA reasonable door panel crush characteristics have been defined (Refs. 6-19, 6-21, and 6-22). Both urethane foam and paper honeycomb door panels have been subjected to impact testing. These tests include torso component impacts and installation of the panels in full scale crash tests. Thus, the importance of energy absorbing panels during side collisions is well established.

Both the urethane foam and paper honeycomb panels have deficiencies which suggest that an alternative panel may be more appropriate for the RSV. Typical torso impact data for a urethane foam (IMPAC III) panel are presented in Figure 6-49. The important point to note is that the foam tends to "bottom" out at about 75 percent collapse of the thickness. Beyond this point, forces rise very rapidly (note force increase near 3.5" of penetration).

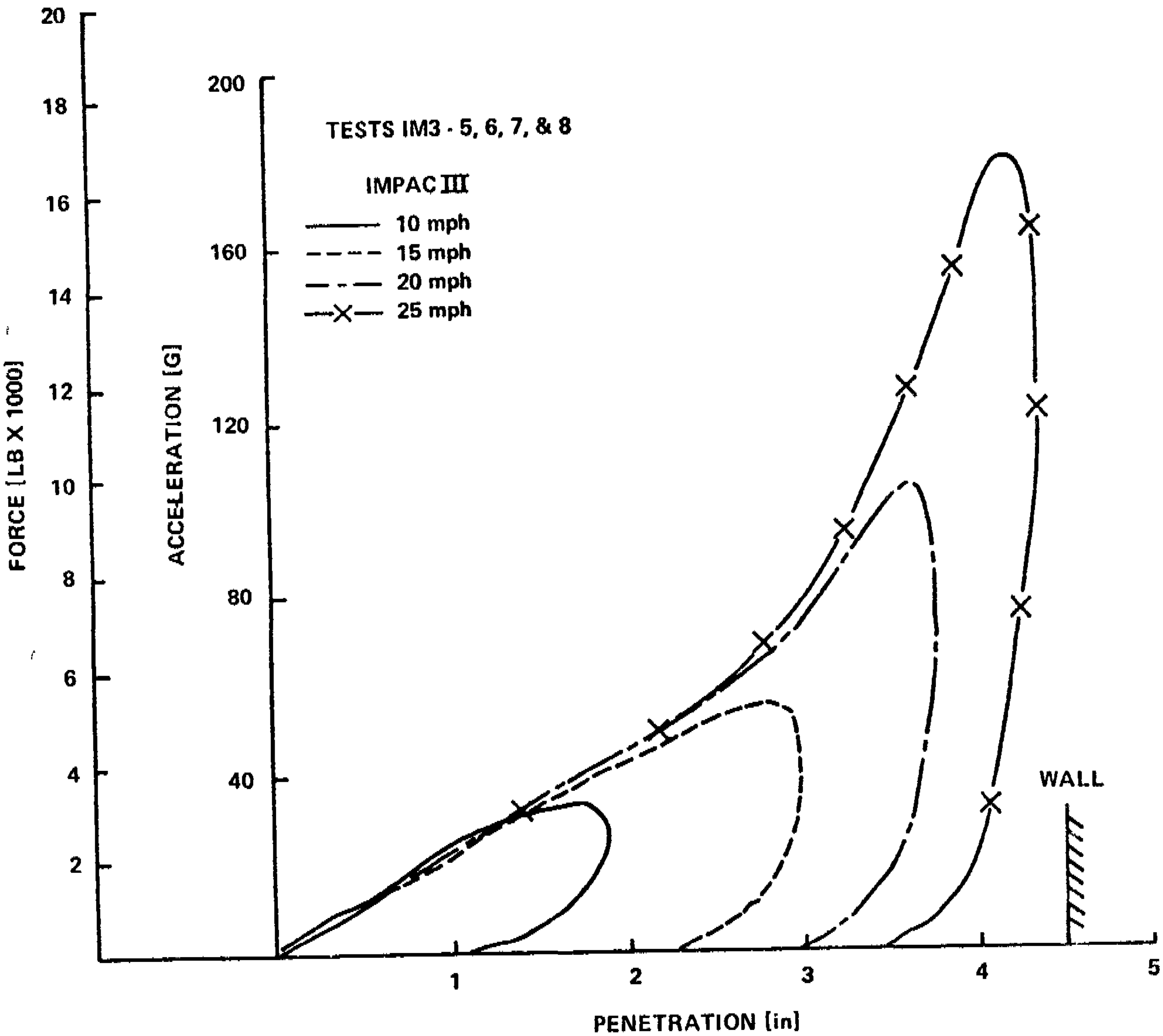


Figure 6-49 FORCE AND ACCELERATION VS. PENETRATION FOR IMPAC III

Similar data for a paper honeycomb panel are provided in Figure 6-50. Here, excellent force deflection characteristics are evident. Reasonably uniform forces are maintained and complete collapse of the panel structure takes place. The importance of full panel collapse in a side wall structure cannot be overemphasized. That is, car width has the greatest effect of any dimension on resultant car weight. For example, achieving full panel collapse rather than 75 percent means that the same interior room and crash protection could be provided with an approximately 2" narrower car.* Although we have not attempted to determine the precise impact on car weight, one should visualize a band of structural material 2" wide covering the entire length of the car. Using this crude method, we estimate the impact to be 50 to 75 lbs. for an RSV size automobile.

From the above it is clear that the collapse characteristics similar to those of Figure 6-50 (paper honeycomb) will be developed into the RSV. But, we note that paper honeycomb structure is probably not the most ideal from a manufacturing viewpoint. For this reason, collapsible metal panels will be considered for the RSV. The basic scheme is shown in Figure 6-51. These panels will be designed to collapse at a load which approximates the force-deflection characteristics of Figure 6-50. These panels will be superior to foam padding because they will take full advantage of the door space available for collapse whereas, as noted previously, foams bottom out at some stroking distance less than the original foam padding thickness. Also the aluminum panel can be designed to produce a more nearly square wave force deflection characteristic rather than the less stroke efficient ramp type characteristic of either the foam or the paper honeycomb. Weight of the aluminum membrane is expected to be comparable to foams. These aluminum

---

*Statement assumes a one inch reduction in panel structural thickness on each side of the car.

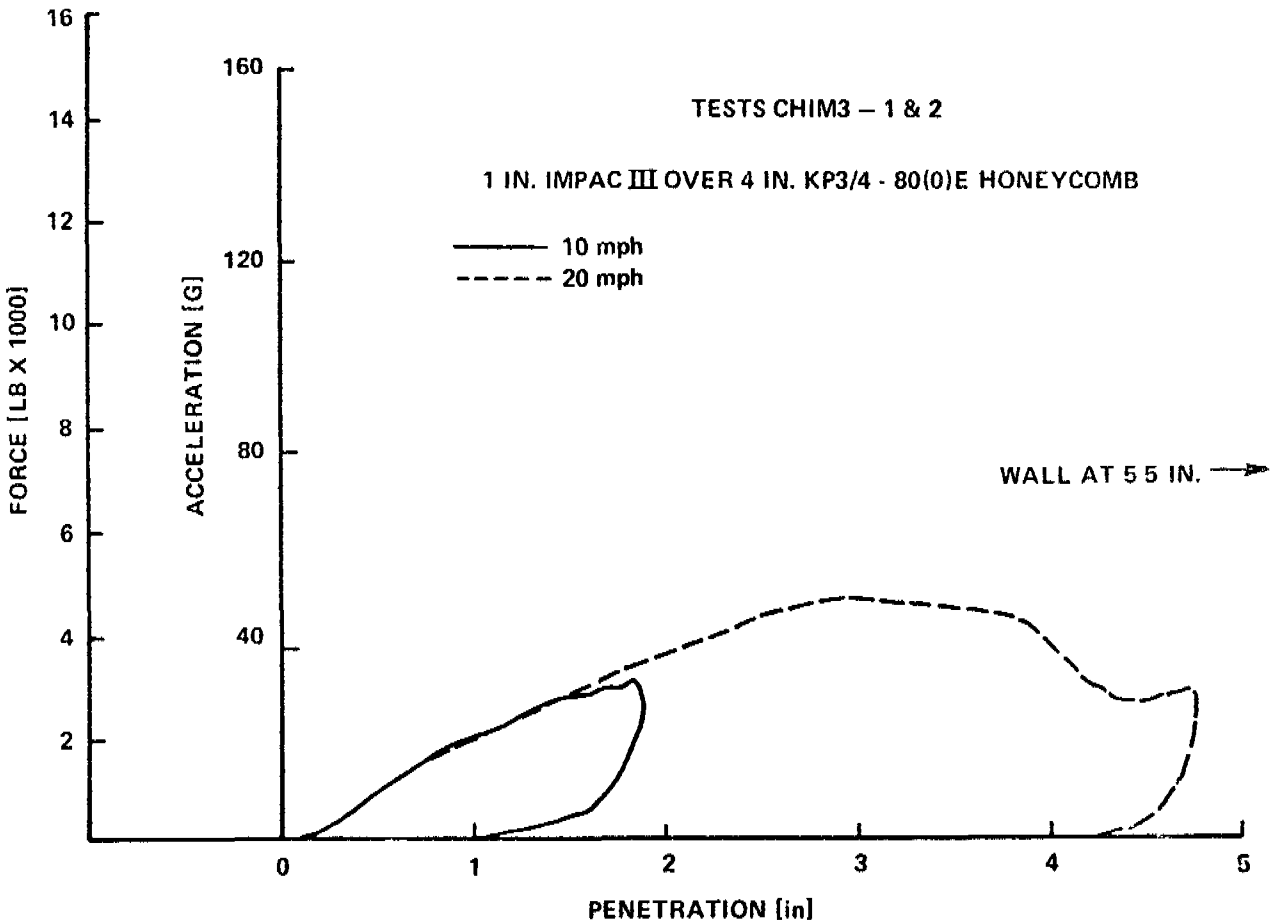


Figure 6-50 FORCE AND ACCELERATION VS PENETRATION FOR 1 IN. IMPAC III OVER 4 IN. KP3/4 - 80(0)E HONEYCOMB

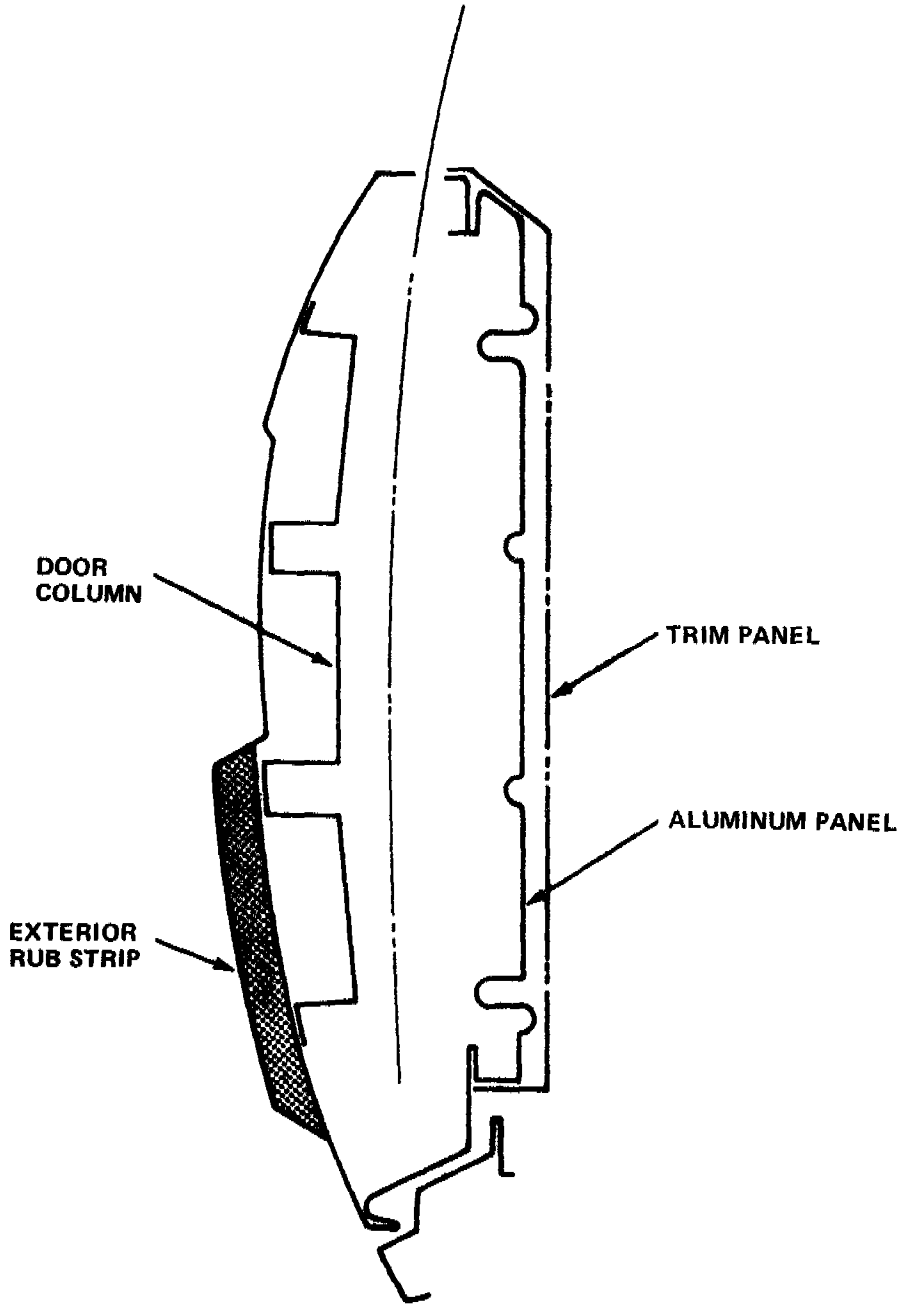


Figure 6-51 TYPICAL CROSS-SECTION OF RSV DOOR SHOWING ALUMINUM PANEL MEMBRANE USED FOR OCCUPANT PROTECTION

panels are bolt-on items which can be easily removed to aid in metal separation during salvage and recycling operations.

Review of moving barrier rear impact data for a Simca 1100 (predecessor to the C-6) indicates that the rear seat backs will fail as a result of occupant loading during the severe rear impact tests. It will, therefore, be necessary to strengthen the seat back; but then the seat tracks will become the weak link in the system. Truck seat tracks will be considered for the C-6 tracks to achieve the desired strength seat tiedowns.

In addition to the above modifications, instrument panel changes will, of course, be necessary if an inflatable (air bag) restraint system is selected, whereas little or no change in this region will be necessary in the event that a belt system is used. An inflatable restraint system will require a strong mounting structure in the instrument panel region to react the restraint system loads. A driver air bag system would require changes in steering column geometry and supporting structure. Knee bars in the instrument panel region may also be required for belt or bag restraint systems. Restraint system technology for the RSV will now be discussed in general and as it influences interior design.

Restraint Systems

The restraint system selected and developed for the RSV will represent an advancement beyond present state-of-the-art restraint systems. These advancements are expected to include as a minimum, increased level of effectiveness, greater occupant comfort, and ease of application if any active participation is required of the vehicle occupant. This discussion briefly explores the range of possible restraint systems and the performance characteristics of the more advanced systems currently under development.

Many types of restraint systems, both active and passive, have been researched, discussed, developed and tested by numerous individuals and organizations during the past decade. The active systems, i.e., those requiring conscious action of the vehicle occupant, if restraint is to be accomplished, include lap belts and lap and shoulder belts, either integrated as one piece or two separate belts which can be hooked together. Passive systems, i.e., those which require no effort on the part of the occupant to deploy the restraint system, include automatic belt systems of various types and inflatable bags or cushions which automatically deploy upon impact or impending impact if anticipatory crash sensors are employed.

In addition to the active or passive types of restraint systems, a third category which is somewhat between the two extremes represented by the other two basic types is the semi-passive system. These systems are not totally automatic in their deployment in that some conscious effort may be necessary, or at least desirable, to increase convenience, such as hooking a belt on a retaining hook to permit easier egress from a passively deployed belt system.

All belt systems, whether active, passive or semi-passive, can include such additional features as load limiters, belt pre-loaders, inflatable belt and inertial locks. All of these items tend to increase either comfort, convenience and/or crash performance of belt restraints. The following discussion of an inflatable belt system, which is considered as a possible candidate system for the RSV, includes descriptions of most of the features that might be found in any advanced belt system.

An advanced belt system is typified by the following adaptation of an inflatable belt to the traditional three-point lap and shoulder belt restraint system. The subsystem elements are schematically illustrated in Figure 6-52 and include the following:

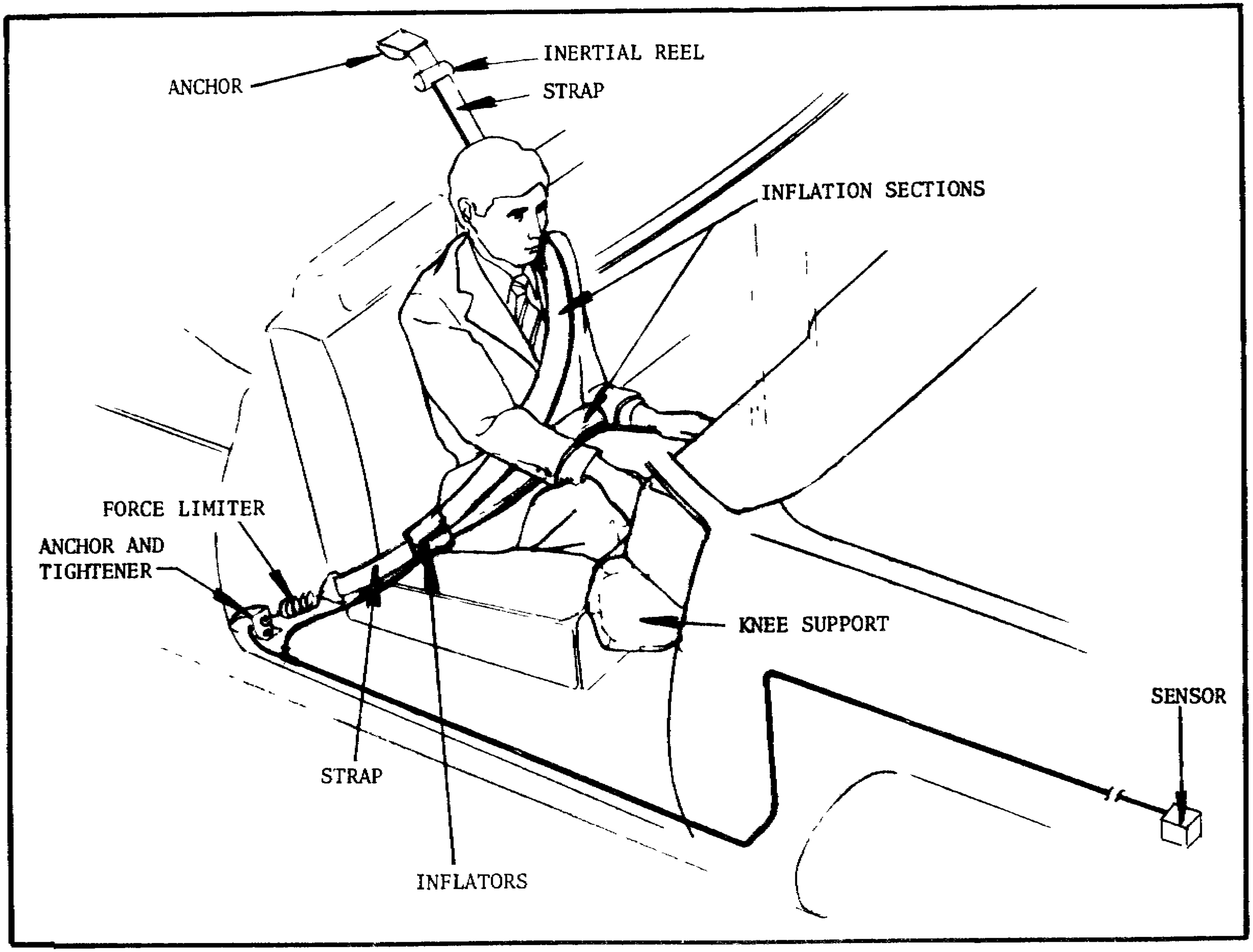


Figure 6-52 SCHEMATIC ILLUSTRATION OF INFLATABLE BELT RESTRAINT SYSTEM COMPONENTS

- crash sensor
- inflator
- belts
- knee support
- inertial reels
- belt tighteners
- force limiters (or energy absorbing) mechanism
- anchors.

All of these items may be used in variations of the basic design but clearly all may not be necessary to insure adequate performance. Therefore, in the event that a belt system is selected for the RSV, the function of each of the above components must be considered in the development of an appropriate restraint system design. Their properties are generally outlined in the following:

Sensor - The sensor must discriminate crashes for which the belts should be inflated. Because inflation volumes are relatively small, noise is unlikely to be a problem; therefore, the system should inflate as rapidly as possible in the event of a severe collision. Sensor discriminating times in the order of 0.005 sec. are desirable and appear to be achievable using electro-mechanical sensors developed for air bag restraint systems. Thus, this part of the system is readily available from previous air bag development programs.

Inflator - The inflator is a relatively simple device which to a certain extent represents a scaled version of that used in air bags. A typical design includes:

- pressure cell
- squib
- burst disk
- manifold.

Shown in Figure 6-53 is a photograph of the various parts of an inflator. Because different pressures may be needed in the shoulder and lap belts, separate units are normally used for each belt. The inflator is under internal pressure (depending on size, this may range from 2000 psi to 4500 psi) and upon receiving a signal from the sensor, the squib fires, raising the internal pressure thereby shearing the burst disk.

Belts - The belts are divided into two parts which must utilize different materials. The inflation segment is an accordion folded cylinder, made from material similar to that used in air bags. Venting may either occur as a result of holes punched in the material or, depending on its porosity, though the material itself. The inflator segments are attached to the anchors through straps similar to those used in current automotive restraint systems.

Knee support - Knee restraint may be provided by either a knee bar or a knee belt. Restraining the knees during forward collisions can eliminate the need for lap belts which do tend to produce high forces in the abdominal cavity. Thus, knee restraint should be considered as an alternative method of loading the occupant.

Knee bars have been developed primarily to provide lower body extremity restraint in conjunction with air bag systems. Their development has been well documented in a number of studies (e.g., see Refs. 6-23 and 6-24). Although knee bars have apparently not been tested with inflatable shoulder belts, there appears to be no reason why such a system could not be advanced.

Knee belts were used in conjunction with upper shoulder straps in the Volkswagen ESV project (Ref. 6-25). In that case the belt was deployed around the knees in the event of a severe forward collision. Again, the system has apparently not been used with an inflatable shoulder belt, but this possibility appears to be one which warrants further exploration.

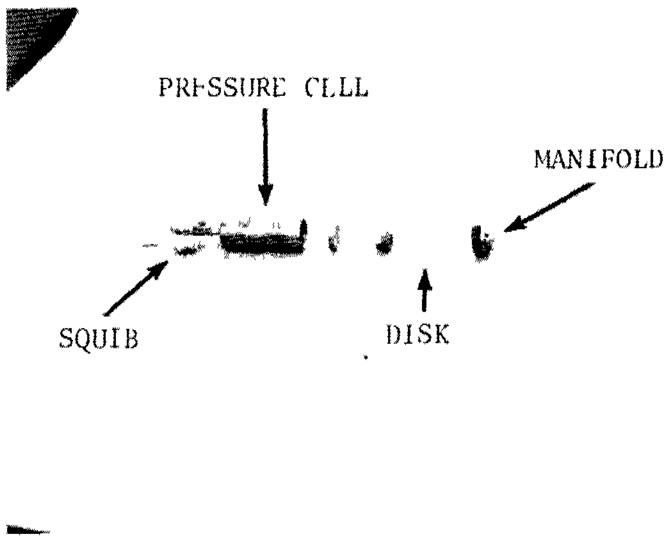


Figure 6-53 COMPONENTS OF BELT INFLATOR

Inertial reels - Inertial reels appear to be important only from the standpoint of convenience and passenger acceptability. Such devices have been available on some recent foreign automobiles and are now required on the upper shoulder strap of all automobiles. The mechanism essentially permits unrestricted torso movement under normal conditions but "locks" the shoulder belt in the event of a collision. Present state-of-the-art systems use either passenger compartment deceleration and/or belt jerk as the mechanism for locking the belt. If belts with belt tighteners are selected for the RSV restraint system, a vehicle acceleration belt lock will be used to provide occupant protection from the effects of an inadvertent actuation of the belt tightening system.

Belt tighteners - One possible advantage of the inflatable belt is that during inflation, it tends to tighten the belts around the passenger. There are, of course, special devices which have been developed to tighten lap/shoulder belts during the early part of the collision (see, for example, Refs. 6-25 and 6-26). The need for belt tightening becomes apparent when one considers the mechanics of a collision. Belts have essentially very low stiffness (primarily due to the fact that they must be flexible in order to be placed around car passengers) which means that they must undergo considerable elongation before a substantial restraining force is developed in the belt. The elongation can occur only as a result of relative displacement between the occupant and the vehicle or if the belt itself is tightened. The tightening characteristics of an inflation belt may be limited because of inflation time and maximum possible pressure. Thus, the alternative of providing for auxiliary belt tightening should be considered as a possibility in the design of an inflatable belt restraint system and a necessity for a non-inflatable belt system.

Force limiters - The function of force limiters in a belt system is to control the maximum force (acceleration) applied to the occupant while at the same time permit the space (dimension) within the passenger compartment to be used effectively in stopping the occupant. Effective force limiters, therefore, provide a means for absorbing the kinetic energy of the occupant. These devices cannot be used effectively with current belts simply because the stiffness of the belt is so low that the entire space within the passenger compartment is expended before adequate loads are developed But, with belt tightening devices (as outlined above) force limiters become an attractive feature for such restraint systems. There are essentially two means for providing force limiters, (1) the anchors can be designed to elongate under the predetermined tensile load, and (2) the nylon webbing could be manufactured to provide the load limiting properties.

Anchor design for this purpose is straightforward, but the best alternative may lie in the webbing material and this possibility is not well understood. Nylon, which is used in webbing, can be manufactured under either semi-drawn or fully-drawn conditions. The draw process essentially stabilizes the stress-strain characteristics of the nylon fibers. Shown in Figure 6-54 are the fiber stress-strain characteristics which result upon drawing. In the semi-drawn process, the fiber is loaded and unloaded according to path ABC. Upon reloading the path CBD will be followed. On the other hand, fully-drawn fibers are loaded and unloaded according to path ADE. Upon reloading, path ED will be followed and the material behaves in an essentially elastic manner. It should be noted that point D nominally represents about 500 percent strain.

Clearly, the characteristics of semi-drawn nylon are more appropriate for restraint systems, yet, all present systems use fully-drawn nylon. The reason for this relates to the historical development of nylon. That is, nylon was developed for the clothing industry where elastic properties are essential. The restraint system industry simply utilized the existing material for belt systems Nevertheless, it would appear that within the RSV program some consideration should be given to the feasibility of developing suitable material properties within the belts themselves, if a belt system is ultimately selected for occupant restraint.

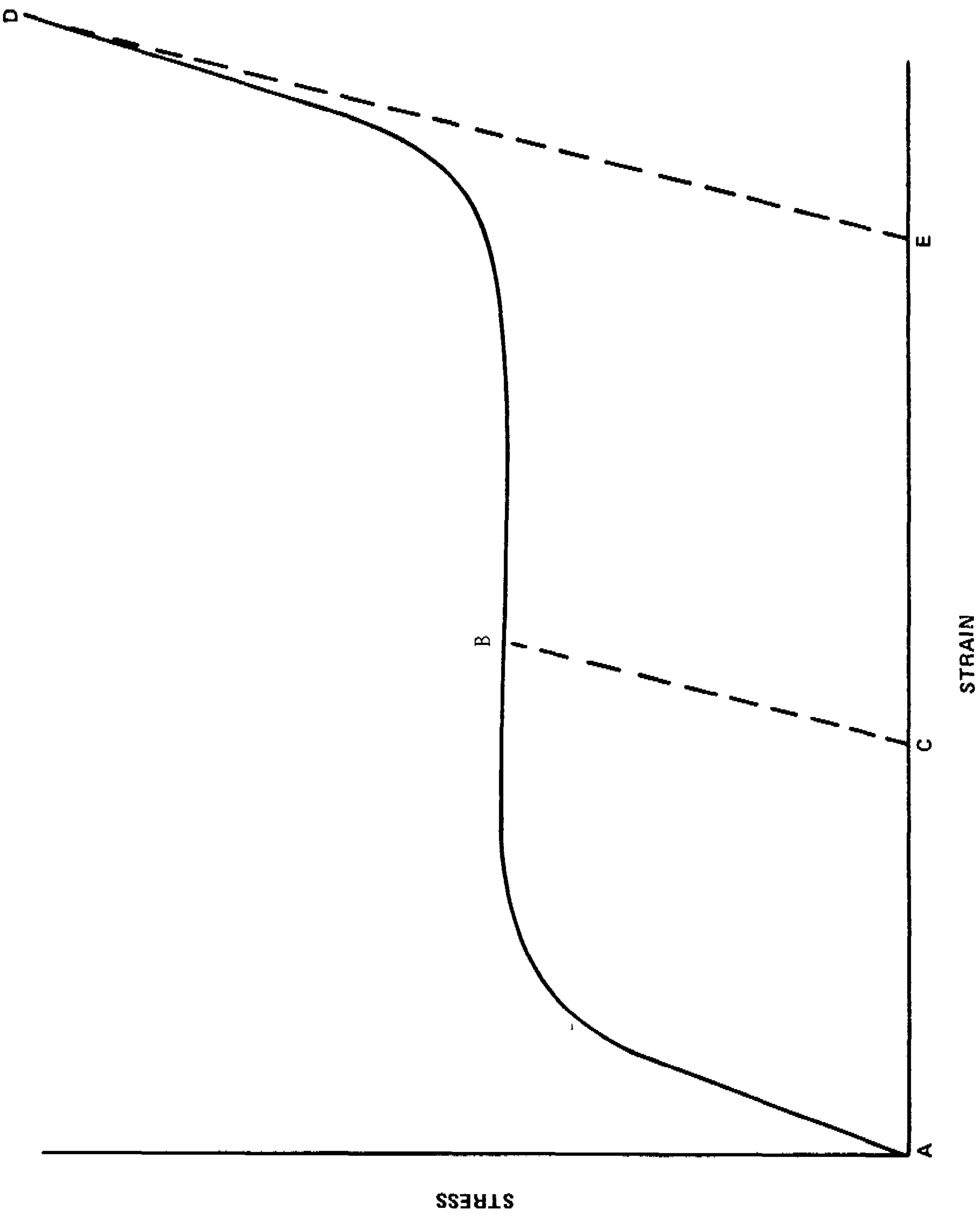


Figure 6-54 STRESS-STRAIN CHARACTERISTICS FOR SEMI AND FULLY DRAWN NYLON FIBERS

Anchors - The primary function of the belt anchors is to secure the system to the passenger compartment. In the event that a belt system is used in the RSV, location of the anchors is deemed very important. That is, the location will greatly influence the way forces are directed to the occupant. But, because of the possible desire to make the system passive, there may be greater restrictions on the choice of anchor locations. Thus, in the final analysis, some compromises between optimum location from the standpoint of force loading and a possible passive requirement may be necessary.

In principal, all the advanced belt system features discussed here could be incorporated, as desired, into a passive belt system which would overcome one of the more objectionable problems of active belt systems, low usage rates. A variety of passive belt systems have been discussed in the literature, e.g., Refs. 6-27 through 6-32. The passive belt system shown in Figure 6-55, taken from Ref. 6-27, solves the anchor point geometry problem by making the belt system and seat an integral unit. In this manner the belt system anchor geometry is independent of seat position within the automobile. This passive system employs under seat motors to automatically apply the belts when the seat is occupied and the ignition is energized.

References 6-28 and 6-29 describe a VW developed passive belt system in which the normal opening and closing of the door removes or applies the belt system. The system of Ref. 6-28 includes a torso belt and a knee bar in the lower instrument panel. With the vehicle door open the torso belt is drawn forward out of the way of the entering occupant. Closing the door then places the torso belt around the occupant. A belt guide ring on the inboard side of the seats keeps the belt tiedown angle from varying with seat position fore and aft. A tunnel mounted retractor keeps a slight tension in the belt system. Refs. 6-29 and 6-32 describe a VW-ESV developed passive shoulder and knee belt system in which the belt system is preloaded for impacts above 15 MPH barrier equivalents. The belt is one continuous loop consisting of a round foam-filled cross-section shoulder portion to eliminate belt induced neck injuries and a wide belt portion around the front of the knees. The shoulder belt upper end is spring loaded

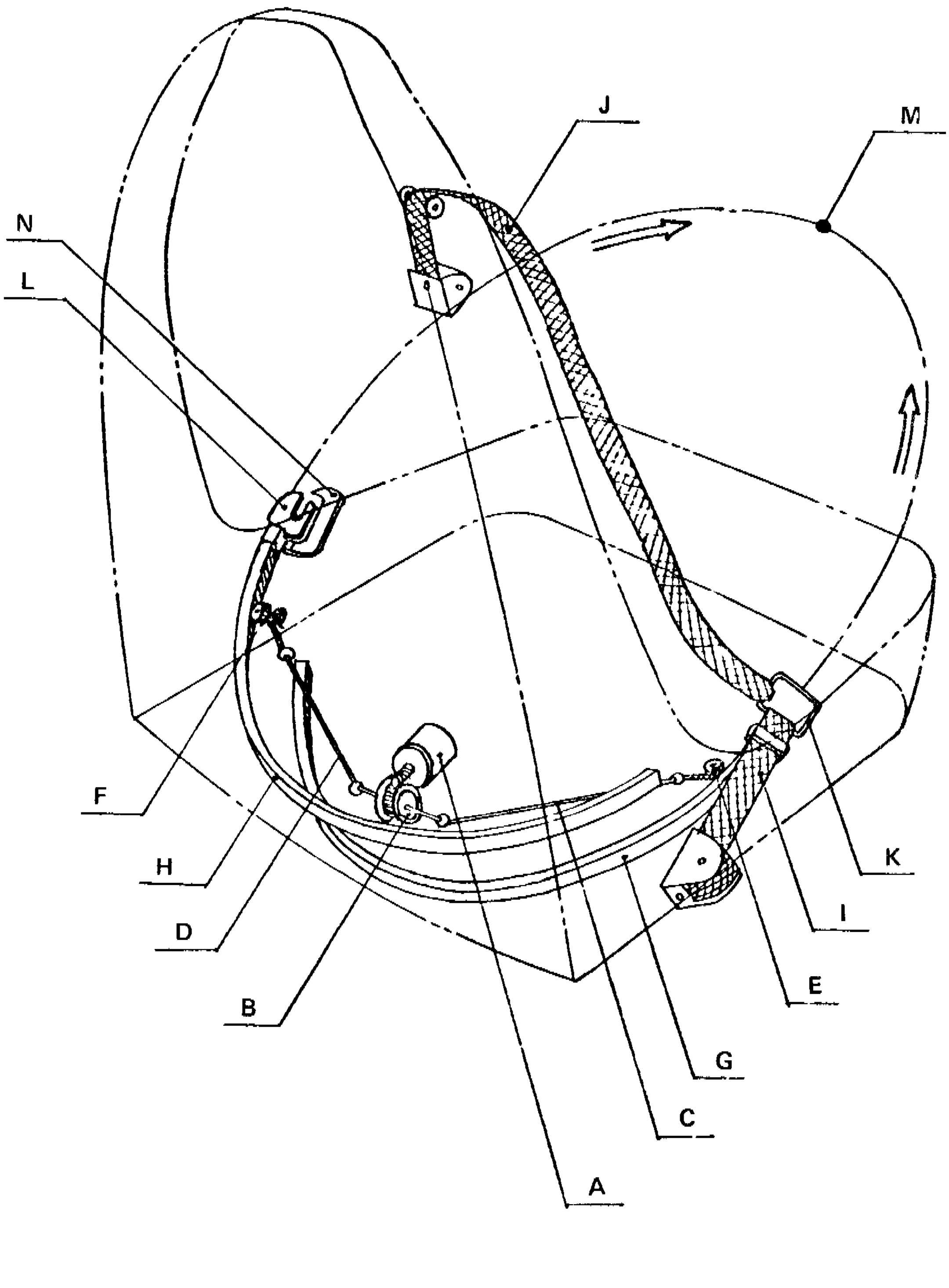


Figure 6-55 INTEGRATED PASSIVE BELT SEAT SYSTEM

forward to the "A" pillar to allow convenient exit and entry to the vehicle. Upon starting the engine, vacuum is used to move the upper end of the torso belt to its aft active position.

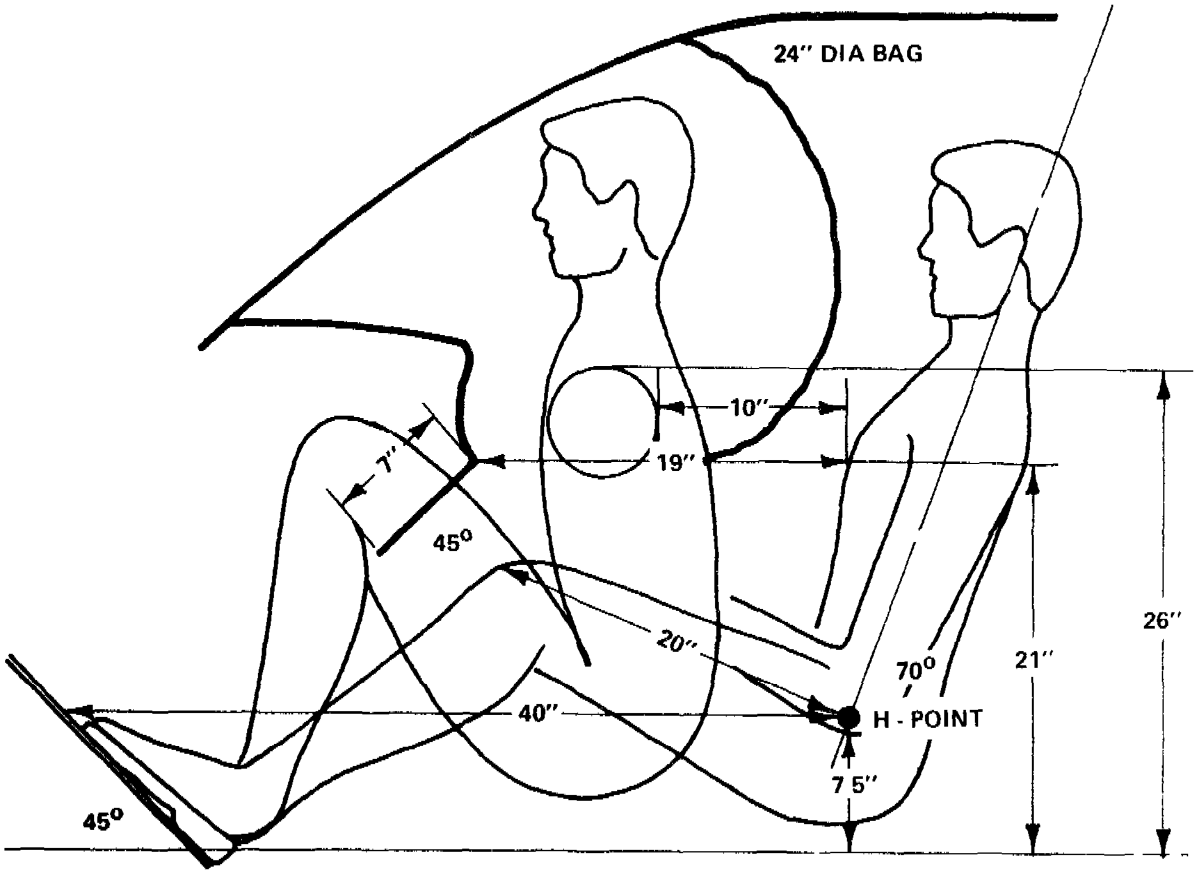
In addition to the passive belt systems discussed so far, Chrysler Corporation has also experimented with passive belt systems as part of their restraint system research. Three different systems that have been investigated by Chrysler would be available for application to the RSV if desired. These systems consist of various torso and torso/lap belt combinations whose application and removal are controlled or activated by door opening and closure. Although these systems are proprietary to the Chrysler Corporation and therefore could not be pictorially displayed in this final report, the designs and the expertise embodied in them are available to this RSV effort.

While the passive belt systems presented and discussed herein certainly do not include all the systems that have been examined by other researchers to date, they do adequately represent the types of systems that have been studied up to this time. The fact that Chrysler Corporation has been one of the organizations researching passive belt systems should be an advantage in our efforts of selecting a suitable restraint system for the RSV.

The alternatives to belt restraint systems are the inflatable air cushion systems, such as those discussed in Refs. 6-33 - 6-38, which are passive devices that deploy at the onset of a crash event. These devices consist of a gas source, which is either stored high pressure nitrogen, a pyrotechnic gas generator or a combination (hybrid) of both, a distribution manifold, an inflatable bag and a crash sensor. Inflatable restraint systems are completely passive and nonobtrusive. Neatly packaged in the steering column hub (driver) or the instrument panel (passenger), air bags are out-of-sight and out-of-mind until called upon to function during a crash.

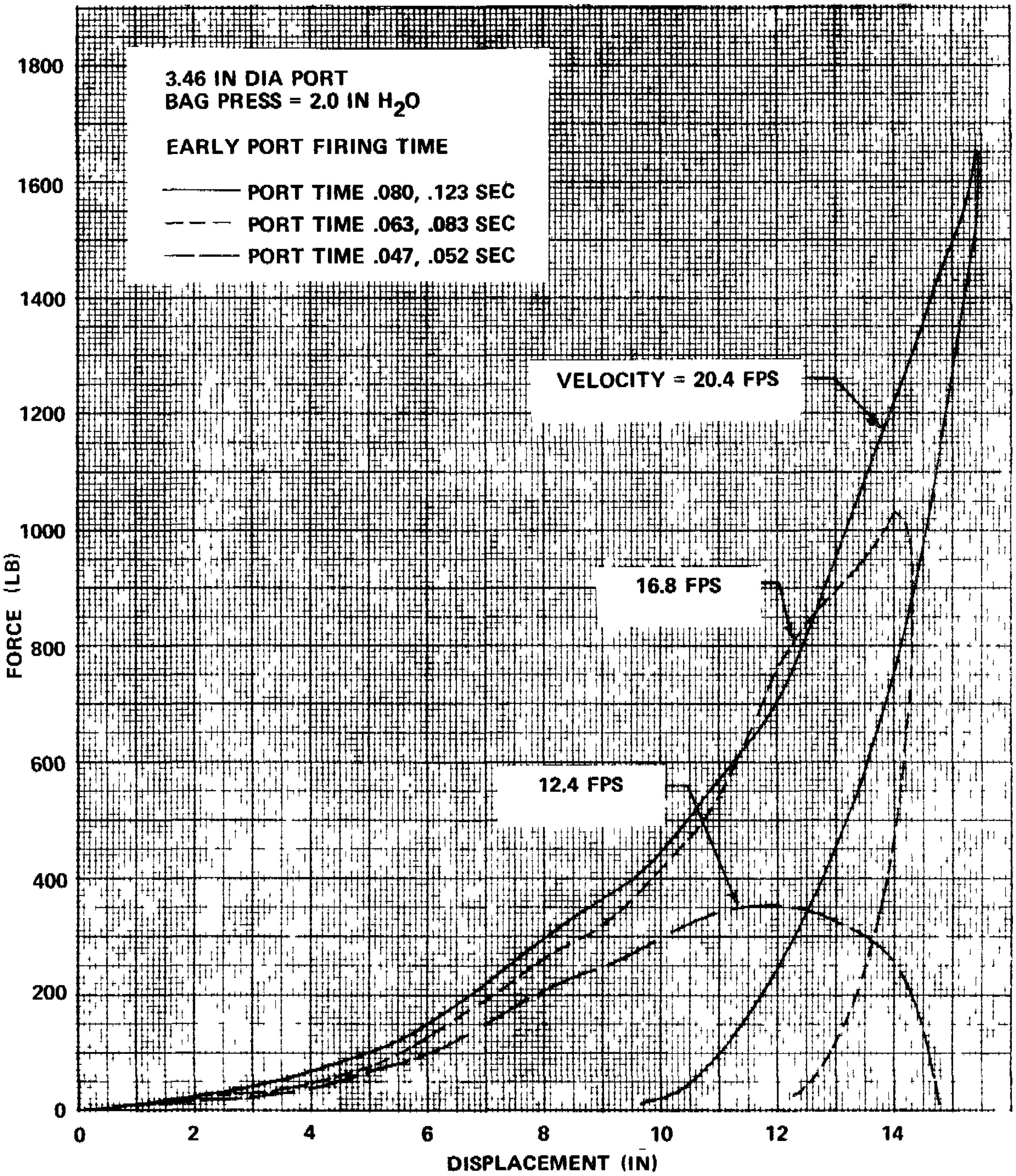
Conventional state-of-the-art air bags are sized to expand and fill the space between the occupant and the vehicle structure, either steering column in the case of the driver or the instrument panel in the case of the passenger. In the case of a small car interior such as the Pinto shown in Figure 6-56, for example, the passenger clearance from the instrument panel is about 19 inches which is the maximum distance available for the air bag stroking. Figure 6-57, taken from Ref. 6-23, shows the force-deflection characteristics of a vented bag representative of state-of-the-art systems currently in limited use. The low stroke efficiency of conventional air bags is readily apparent from the data shown in Figure 6-57. The very slow restraining force buildup as a function of bag deflection inefficiently utilizes the available stroking distance thereby reducing the crash energy dissipation capability of the restraint system substantially from the theoretical potential of an ideal system. The data shown in Figure 6-57 indicate a stroke efficiency of the order of 30% which means that 70% of the theoretical potential performance is not realized. A 30% stroke efficiency for compartment dimensions as shown in Figure 6-56 for the Pinto results in the equivalent of 13 of the 19 inches available being unused in the occupant deceleration process.

A restraint system design which achieves a high stroke efficiency while retaining the favorable load distribution attributes of an air cushion is the bag/bolster concept. Such a system has been under development at Calspan Corporation for some time now as part of an advanced air bag system for smaller size automobiles. Figure 6-58 indicates the basic components used in the system. The bolster support arms are two G.M. energy absorbing steering column units with additional strength provided by honeycomb plugs. Total strength per strut is approximately 900 lbs with a stroke of 6 inches. A cylindrical air bag is attached to the perforated, collapsible gas manifold which is positioned 9 inches out from the instrument panel as shown in Figure 6-56 within the Pinto test vehicle passenger compartment.



PINTO – 50th MALE MID SEAT

Figure 6-56 ADVANCED AIR BAG SIMULATION INPUTS



Dummy Force — Displacement Data

Figure 6-57 VENTED AIR BAG PENDULUM TEST RESULTS, VARIOUS VENT PORT SIZES

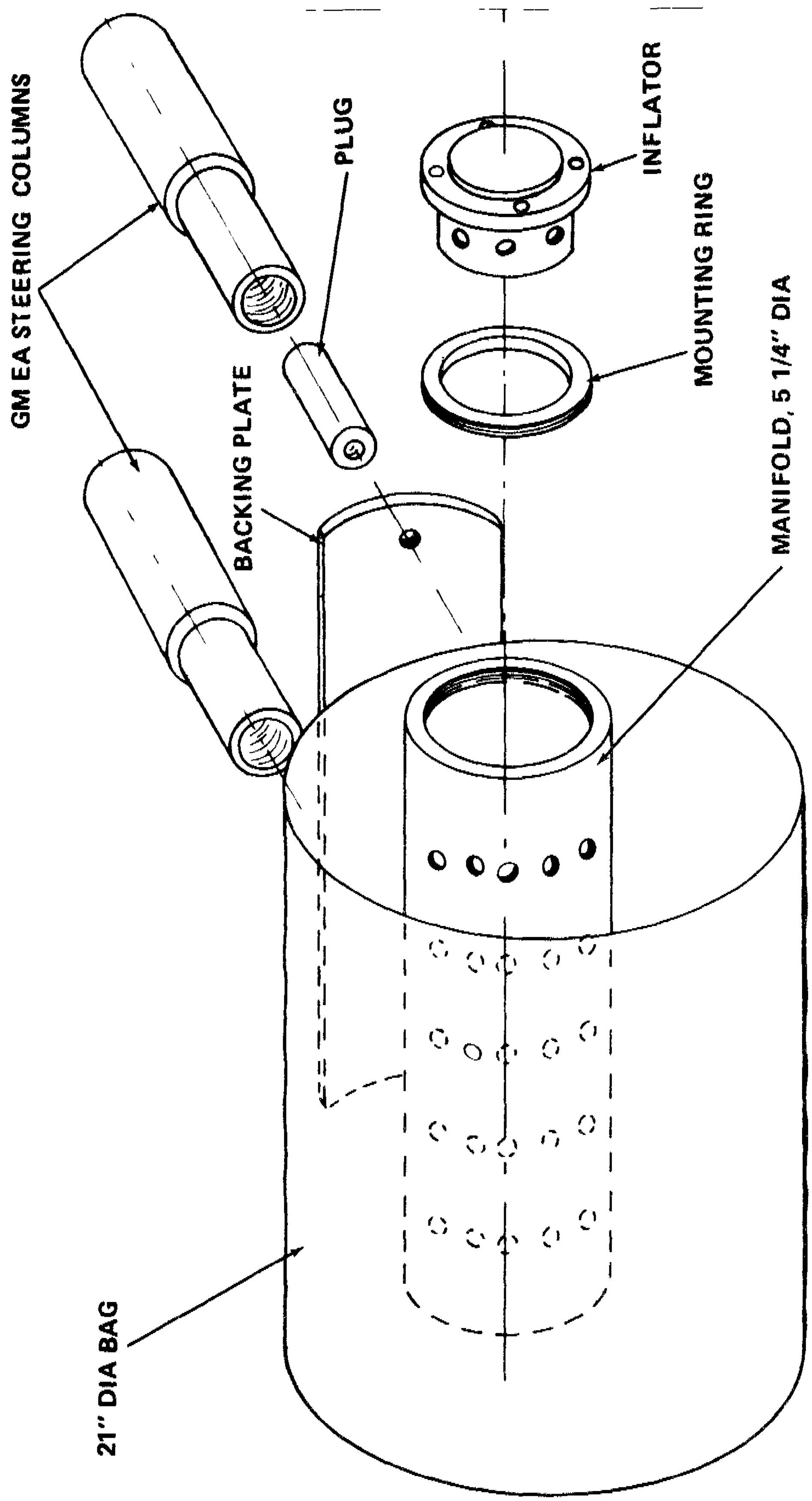


Figure 6-58 SKETCH OF AIR BAG SYSTEM

Figure 6-59 presents photographs of the bolst r mockup in a Pinto. An obvious objection to this type of restraint system is its obtrusiveness in that it hinders somewhat normal ingress/egress of the occupant. Methods are being considered to move the bolster aside during ingress/egress of the vehicle. One such scheme would provide hinging to permit lifting the bolster upward into a position blocking the occupant's field-of-view through the windshield thereby encouraging the proper placement of the bolster after entry to the seated position. This convenience feature does somewhat dilute the system's degree of passivity although it is felt that the optional nature of the lifting operation coupled with the fact that there is a strong motivation (in order to see forward) to lower the bolster to its deployed position does probably satisfy the intent of a passive restraint, namely nearly 100% utilization. Obviously, with considerable increase in complexity the movable bolster could be automated, perhaps through the door opening process, in which case passivity would be retained.

Maximum Restraint System Performance

The bag/bolster system under development at Calspan as described above appears to offer the best performance of all the inflatable systems investigated to date. Although test work is not complete on the system, preliminary indications are that a 50th percentile occupant may be adequately protected to 50 MPH in a straight-on frontal impact as indicated in the predicted performance map shown in Figure 6-60. One of the deficiencies of the bag/bolster system is its degradation in performance with impact angularity, a fault shared by most, if not all, other air bag systems developed to date. In addition, inflatable systems in general will not prevent occupant ejection. Consequently, as stated previously in this RSV effort, lap belts are, in our opinion which is based on ejection and rollover statistics, essential as part of any air bag restraint system that may be selected for the RSV.

Figure 6-59 **PINTO BOLSTER MOCKUP, 50TH AND 95TH PERCENTILE MALE OCCUPANT SIZES**

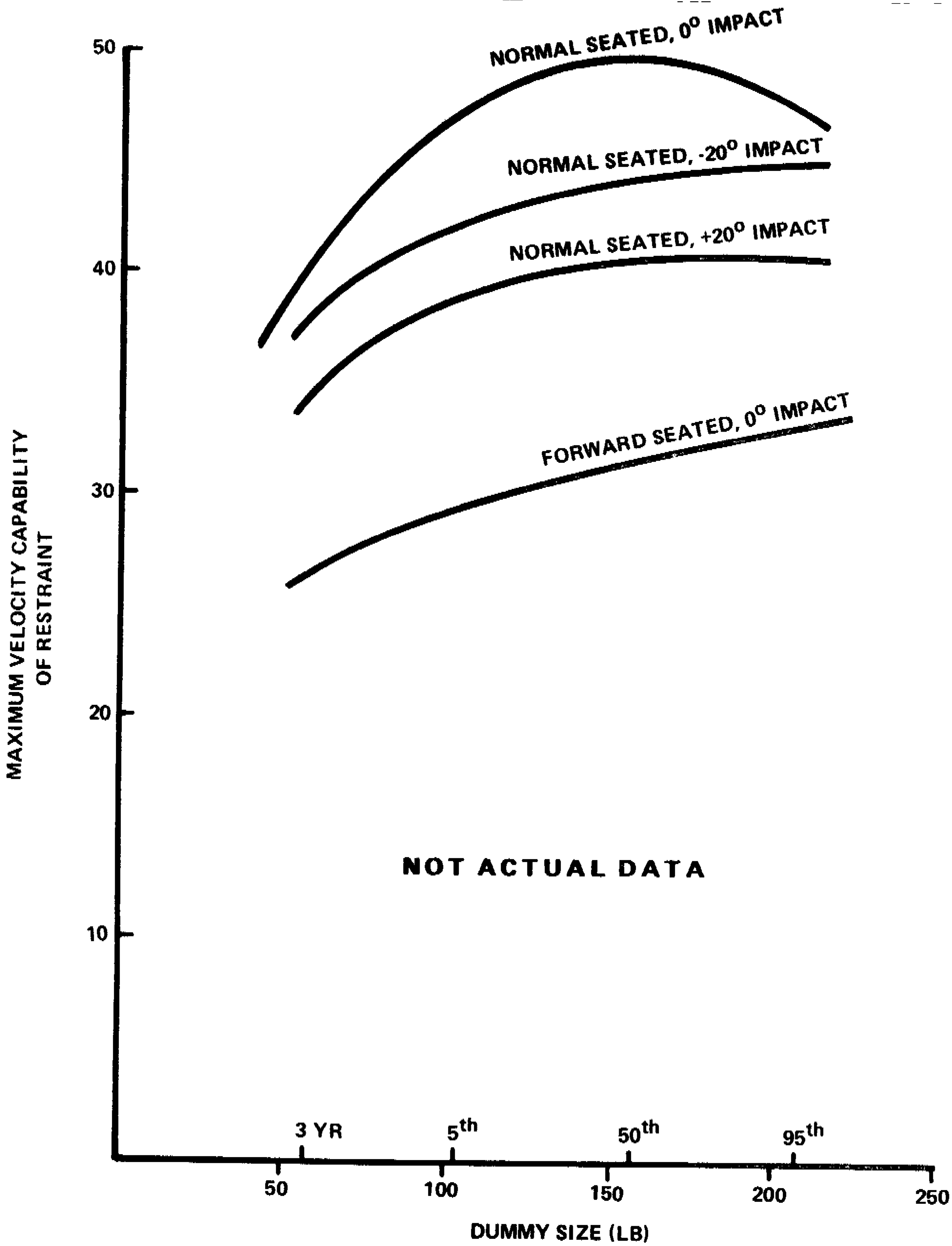


Figure 6-60 EXAMPLE OF PERFORMANCE ENVELOPE

The best performing belt system for which experimental substantiation has been published appears to be the passive shoulder-knee system developed on the VW-ESV program (Refs. 6-29 and 6-32) and discussed earlier in this section. This system includes belt force limiters and belt preloading. Sled tests conducted by VW on the system indicated successful performance (injury criteria limits not exceeded) at 50 MPH whereas conventional shoulder and lap belts with force limiters and preloaders, also tested by VW, resulted in a Severity Index of 960 at 30 MPH indicating that the SI limit of 1000 would be exceeded at impact speeds substantially below 50 MPH.

Although the VW studies indicate superior performance for the shoulder-knee belt system in straight-on sled tests, it is not known how effective this belt arrangement would be at preventing occupant ejections. The lack of a lap belt in this system may be a serious deficiency in the event of a rollover or highly angular impact. It would appear that considering head-on impacts only, inflatable or belt restraint systems have about the same maximum impact velocity performance and that the choice of system may be made on the basis of the more realistic angular and rollover impacts.

Vehicle Structural Requirements Related to Restraint System Choice

Finally, another consideration in evaluating the various trade-offs between inflatable and belt restraint systems is the differing structural requirements imposed upon the vehicle by the two types of systems. A bag/bolster system will require a nearly zero compartment intrusion limit for the instrument panel region of the vehicle if the required bag/bolster geometry and positioning relative to the occupant are to be maintained. By contrast, the belt system will not be critically dependent upon fire wall or instrument panel integrity and can in all probability tolerate several inches of compartment intrusion without jeopardizing its effectiveness. A belt system would, of course, require strong anchor points in the vehicle structure but it is felt that these can be readily provided in a vehicle body that will include strengthened floor and side structures to achieve the crashworthiness goals of the RSV.

In concluding this restraint system discussion it should be recognized that the structural implications of the two different types of restraint systems may play a significant role in restraint system selection for the RSV. As has been stated elsewhere in this report, vehicle structural crashworthiness performance and restraint system performance are interrelated and consideration of one requires consideration of the other if an optimum vehicle system is to result. Therefore, evaluating the trade-offs considering the restraint system and the vehicle structure may result in a definitive choice for the restraint system.

6.4 Discussion

From the information presented in this report volume it is apparent that we believe that the performance requirements deemed appropriate for the RSV can be developed into an existing automobile in a straightforward manner. There are a number of reasons for this; but, basically the most important factor is that the C-6 represents a current application of modern automotive technology. The weight of the base vehicle in relation to its occupant/cargo capacity is excellent. Moreover, the transverse, front engine drive system allows considerable design flexibility. Although no major problems are anticipated it should be emphasized that development of the final RSV design still requires substantial engineering and design effort.

The expected structural changes are defined at the conceptual level and appear rather modest in relation to expected changes in the base vehicle crash performance. But, determining the detailed design suitable for the RSV will undoubtedly uncover numerous complications. Resolution of these complications will likely, in certain instances, suggest the need to re-evaluate the suitability of the original specifications. A possible example is provided by the soft face bumper and the headlight mounting system. Recessing the headlights in the soft face is felt to be unacceptable because of climate consideration (snow) while there may be legal restrictions to placing scratch resistant plastic covers on recessed headlights. Therefore, we have suggested consideration of schemes where the headlights would move rearward while the bumper deforms. After further investigation it may become apparent that this approach is unnecessarily cumbersome and, provided that lighting requirements are maintained, the transparent shield method would be far more satisfactory in relation to safety (particularly pedestrian protection). In this case, naturally redefinition of the requirements would be in order. Numerous other examples which might result in possible future redirection could readily be listed.

The greater challenge in the RSV development effort relates to the primary restraint system. As noted in the restraint system discussion, substantial levels of technical performance appear to be possible with either the advanced belt or air cushion approaches. Each has decided advantages and disadvantages. Within the framework (and limited resources) of Phase I it was not possible to fully explore the ramifications each would have on the RSV design and subsequent performance characteristics. We note, however, that the lightweight vehicle with high crash performance goals envisioned by us as appropriate for the mid-1980's must not limit compartment intrusions to previous ESV specification values (i.e., in the order of 3 to 4 inches). If indeed, a given restraint system requires minimal intrusion, then the structural weight impact could be substantial. It is particularly this variable which must be considered in detail when selection of the particular approach is made in Phase II.

The matter of intrusion is further illustrated by side impact test results recently developed by Calspan under contract for NHTSA. During a number of vehicle-to-vehicle side impact tests, FMVSS 208 dummy injury criteria have been satisfied with unrestrained dummies* in the struck vehicle while at

---

*Part 572 dummies were used in these tests.

the same time 10 inches or more of side wall intrusion has taken place. Although these results have been obtained with standard size cars, they have significant implications for smaller cars.

It is common practice to relate available side wall crush to door dimensions. Because the door walls on smaller cars are greatly reduced in thickness from those of larger cars (frequently the dimensional reduction approximates the weight ratios), side impact collisions between smaller cars are felt to be more challenging than those between larger cars. But, if intrusions of the order of 10" are allowable while still satisfying injury criteria then it appears that substantial side impact crashworthiness is achievable during vehicle-to-vehicle impacts involving smaller cars. This results because the distance parameter in small car side impacts would not be much different than that of larger cars. (Note, this distance is the sum of side wall and intrusion dimensions.) In addition, the energy management requirement is greatly reduced (in proportion to weight) with the smaller cars.

In the conceptual definition effort we have not placed great attention on vehicle weight. The reasons for this are twofold -- (1) precise weight analysis requires design development well beyond the conceptual level and (2) the favorable base vehicle weight suggests that the 3000 lb target is readily obtainable. It is our feeling that the key to meeting the objectives of the RSV program lie with the selection of a reasonable candidate base vehicle. In this respect, the C-6 is certainly one of the best of a limited number of alternative candidate automobiles. Note that with the base vehicle weight of 2300 lbs a 30 percent weight increment would be required in order to exceed the 3000 lb contract specification limit. We know of no instances ever within the ESV projects (where weight was an apparent problem) which resulted in weight increments of this relative magnitude between the base and the delivered vehicle. Thus, there exists considerable assurance that using the approach outlined in this volume will result in an RSV below the 3000 lb limit. We also again emphasize that this car will be a 4-5 place family automobile.

We do not, however, view weight as a casual problem. Indeed, weight and its control must be a critical factor in the eventual selection of design alternatives (e.g., note previous discussion relative to door padding material and vehicle width requirements). With such continuous scrutiny it is felt that the basic scheme outlined herein can result in an RSV meeting the basic specifications provided in Volume III, having a curb weight near 2600 to 2700 lbs.

Finally, it is important that the recycling capabilities of material candidates be again emphasized. A common thread in the overall concept is that the basic materials which are incompatible (in relation to recycling) be easily separable prior to scrap processing. Witness the use of aluminum only in the hood, trunk and inner door panel body structural elements. HSLA steel which is metallurgically compatible with mild steel is used in all other body elements where disassembly would be impractical. Furthermore, the plastic soft face is intended to be an easily removable and basically a recyclable element.

REFERENCES

6-1. Rice, R. S., "Measuring Car-Driver Interaction with the g-g Diagram," SAE Paper 730018, January 1973.

6-2. Sorsche, J. H., Enke, K., and Bauer, K., "Some Aspects of Suspension and Steering Design for Modern Compact Cars," SAE Paper 741039, October 1974.

6-3. Kizu, R., "The Design Concept and Techniques of Suspension and Steering for 1974 Toyota Corona," SAE Paper 741040, October 1974.

6-4. Jones, I. S., "Road Accident Studies with Particular Reference to the Handling and Stability Characteristics of Cars," Doctoral Thesis, Traffic Studies Group, University College, London, August 1973.

6-5. Kuebler, J. E., "Tire Companies Strive to Shrink or Eliminate the Spare," Rubber World, June 1974.

6-6. Keen, H., "The Total Mobility Tire," presented at the Third International Technical Conference on Experimental Safety Vehicles, Washington, D. C., June 1972.

6-7. Lee, Walter, "Possibility of 'Spare Tire Elimination' by Use of Dual Compartment Tires," presented at the SAE Summer Meeting, Atlantic City, New Jersey, June 1959.

6-8. Elliot, D. R., Klamp, W. K., and Kraemer, W. E., "Passenger Tire Power Consumption," SAE Paper 710575, June 1971.

6-9. Roland, R. D., Rice, R. S., and Kakaley, E., "Tire Properties Effects on Passenger Car Handling," SAE Paper 741108, October 1974.

6-10. Roland, R. D., Rice, R. S., and Dell'Amico, F., "The Influence of Tire Properties on Passenger Vehicle Handling," Volume II, Calspan Report No. ZM-5350-K-2, June 1974.

6-11. Schiappati, A., "Active Safety, A Contribution to the Study of the Vehicle-Driver System," presented at the Third International Technical Conference on Experimental Safety Vehicles, Washington, D. C., June 1972.

6-12. Enke, K., "Analysis of the Steering Behavior of Automobiles by Tests With and Without Man as Driver," presented at the Second International Technical Conference on Experimental Safety Vehicles," Sindelfingen, Germany, October 1971.

References (Contd.)

6-13. Lincke, W., Richter, B., and Schmidt, R., "Simulation and Measurement of Driver Vehicle Performance," SAE Paper 730489, Detroit, May 1974.

6-14. Richter, B., "Driving Simulator Studies: The Influence of Vehicle Parameters on Safety in Critical Situations," SAE Paper 741105, Toronto, October 1974.

6-15. Finn, B. J., Riede, P. M. and Roller, A. E., "Handling Characteristics of the General Motors Experimental Safety Vehicle," SAE Paper 730079, January 1973.

6-16. Brayman, A. F., "Standards Enforcement Testing FMVSS 202, 212 and 301, 1971 Simca 1204," Report No. ALL-CAL-74-005-YB-3084-K-5, June 1971.

6-17. Romeo, David J., "Vehicle Acceleration Data Obtained During Barrier Crash Standards Enforcement Tests," Calspan Report No. YB-3084-K-99, June 1971.

6-18. Merz, E. J. and Greene, J. E., "Application and Testing of an Internal Air Cushion Bumper on a Structurally Modified Automobile," Presented at the 1975 SAE Automotive Engineering Congress and Exposition, Cobo Hall, Detroit, Michigan, February 24-28, 1975.

6-19. Miller, P. M. and Greene, J. E., "Development and Evaluation of a Structural Crashworthiness System for a Standard Size Automobile," Calspan Corporation Report No. ZM-5177-V-2, June 1974. Prepared for DOT, NHTSA under Contract No. DOT-HS-053-2-487.

6-20. Pavlick, Michael J., "Development of Energy Absorbing Automotive Structures Using Scale Model Test Techniques," 3rd International Conference on Passive Restraints, Troy, Michigan, July 10-12, 1974, SAE No. 740570.

6-21. Greene, J. E., "Basic Research in Crashworthiness II - Side Impact Tests of Unmodified Vehicles," Calspan Corporation Report No. YB-2987-V-9, February 1973.

6-22. Greene, J. E., "Basic Research in Crashworthiness II--Development and Testing of Vehicle Side Structure Modifications," Calspan Report No. YB-2987-V-14, May 1973.

References (Contd.)

6-23. Shoemaker, N. E., "Research and Development of an Advanced Inflatable Occupant Restraint System," Calspan Report No. YB-2985-V-1, September 1971.

6-24. Romeo, D. J. and Rose, R. A., "Development of a Rear Seat Inflatable Occupant Restraint System," Calspan Report No. ZM-5028-K-1, September 1972.

6-25. Fiala, E., Report on Volkswagen ESV, Report on the Third International Technical Conference on Experimental Safety Vehicle, May 30 - June 2, 1972, Washington, D. C., pp. 2-198 through 2-212.

6-26. Tarriere, C., Mauron, G., and Ventre, P., "French Developments in Original Deployable Systems (with reference to safety belts)," 2nd International Conference on Passive Restraints, Detroit, Michigan, May 22-25, 1972, SAE Paper No. 720410.

6-27. Takada, Juichiro, "Seat Belt Type Passive Restraint System," 2nd International Conference on Passive Restraints, Detroit, Michigan, SAE No. 720680, May 22-25, 1972.

6-28. Seiffert, U., Klaus, O. and Paitula, H., "Description of the Volkswagen Restraint Automatic (VW-RA) Used in a Fleet Test Program," Automotive Engineering Congress, Detroit, Michigan, February 25 - March 1, 1974, SAE No. 740046.

6-29. Willumeit, H. P., "Passive Preloaded Energy-Absorbing Seat Belt System," 2nd International Conference on Passive Restraints, Detroit, Michigan, May 22-25, 1972, SAE No. 720433.

6-30. Seiffert, U. W., Carbon, E. and Ristau, H., "Three Point Energy-Absorbing Seat Belt System with Combined Vehicle- and Webbing-Sensitive Emergency Retractor," 2nd International Conference on Passive Restraints, Detroit, Michigan, May 22-25, 1972, SAE No. 720434.

6-31. Johannessen, H. G. and Yates, G. A., "Passive and Semi-Passive Seat Belts for Increase Occupant Safety," 2nd International Conference on Passive Restraints, Detroit, Michigan, May 22-25, 1972, SAE No. 720438.

6-32. Willumeit, H. P., "Status Report of ESV Work and Conclusions," Report on the Fourth International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, March 13-16, 1973.

References (Contd.)

6-33 Martin, J. F. and Romeo, D. J., "Preliminary Vehicle Tests - Inflatable Occupant Restraint Systems," Calspan Corporation Report No. YB-2990-K-1, -K-2, March 1971.

6-34 Campbell, D. D., "Air Cushion Restraint Systems Development and Vehicle Application," 2nd International Conference on Passive Restraints, Detroit, Michigan, May 22-25, 1972, SAE No. 720407.

6-35 Pflug, J. A., "Air Cushion Systems for Full-Sized Cars," 2nd International Conference on Passive Restraints, Detroit, Michigan, May 22-25, 1972, SAE No. 720408.

6-36 Seiffert, V. W. and Borenius, G. H., "Development Problems with Inflatable Restraints in Small Passenger Vehicles," 2nd International Conference on Passive Restraints, Detroit, Michigan, May 22-25, 1972, SAE No. 720409.

6-37 Klove, E. H., Jr. and Oglesby, R. N., "Special Problems and Considerations in the Development of Air Cushion Restraint Systems," 2nd International Conference on Passive Restraint Systems, Detroit, Michigan, May 22-25, 1972, SAE No. 72041.

6-38 Biss, D. J. and Shoemaker, N. E., "Investigation of New Concepts of Air Bag Restraint Systems for Front Seat Passengers," Calspan Corporation Report No. ZM-5115-V-1, October 1973.